R-1428

DAVIDSON LABORATORY

Report SIT-DL-70-1428

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A MODEL STUDY OF THE HYDRODYNAMIC CHARACTERISTICS OF A SERIES OF PADDLE-WHEEL PROPULSIVE DEVICES FOR HIGH-SPEED CRAFT

by

Gilbert A. Wray

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prepared for

Department of Defense
under
Contract DAAE-07-69-C-0356

(Project Themis)

STEVENS INSTITUTE OF TECHNOLOGY
CASTLE POINT STATION
HOBOKEN, NEW JERSEY

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Approved

I. Robert Ehrlich, Manager
Transportation Research Group

ABSTRACT

This report covers an investigation of the hydrodynamic characteristics of a series of scale models of paddle wheels with fixed radial blades, designed for speeds in excess of 20 knots.

The results indicate that a six-bladed wheel has higher propulsive efficiency and thrust than a twelve-bladed wheel. Peak efficiency is in the neighborhood of 41 percent and occurs at slip values of 30 to 40 percent. Thrust increases with immersion depth, within the range tested (16 percent of the wheel diameter immersed). There is a slight break in the thrust curve over a span of 10-percent slip, after which the thrust again increases with increasing slip.

There is evidence of scale distortion, and it is felt that the present model, with a scale factor of 8.5 to 1, may have been too small.

Keywords

Hydrodynamics
Amphibians
Paddle Wheels
Propulsion

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NOMENCLATURE

D	outside diameter of paddle wheel
Fr	Froude number , $\frac{V}{\sqrt{gD}}$
K_Q	torque coefficient
K_T	thrust coefficient
N	rotation speed of wheel (rpm)
Q	torque
T	thrust of paddle wheel
V	relative velocity between water and blade tip speed (i.e., blade tip speed minus advance velocity of vehicle)
V_a	inlet or advance velocity (knots)
V_o	inlet or advance velocity (ft/sec)
V_1	water velocity at wheel blade
V_2	exhaust velocity
b	span (width) of blade
d	blade immersion , $\frac{D}{2} - h$
g	gravitational constant
h	height of wheel axis above free water surface
$\dot{m}$	mass flow rate of water
n	rotation speed of wheel (rps)
r	effective radius to midpoint of blade, $(\frac{D}{2} + h)\ 1/2$
s_r	slip , $1-\lambda_1$

Subscripts

m	model properties
p	prototype properties

Greek Letters

η_p	propulsive efficiency
λ_1	advance ratio
ρ	mass density of water
θ	angle included by 1/2 immersed arc at radius r , $\cos\theta = \frac{h}{r}$

BACKGROUND AND INTRODUCTION

Historically, the use of paddle wheels of one form or another, to propel a vessel, can be traced back to the days of the Egyptian and Roman Empires. The use of paddle-wheel boats was first recorded in 1472, in the thesis "De Re Militari," by R. Valturius.

With the invention of the steam engine and later the diesel engines -- both of which were low-speed devices and hence well suited to then current designs -- the state of the art progressed. By the 1880's the wheel designs had reached a high state of development. A 246-ft long vessel of the BELLE type, built for use on the Thames River, achieved a measured peak propulsive efficiency of almost 60 percent, at a speed of 12 knots over a measured mile.[1,2,3] The cross-channel packets of 1880-1890 were paddle propelled, and two of these ships, the PRINCESS HENRIETTA and the PRINCESS JOSEPHINE, which were 300-ft long, attained measured-mile speeds of 21 knots.

Studies of paddle wheel-propelled vessels[4-9] have revealed that they were successfully used in shallow draft, weed-infested areas. They fell into disuse over the years, for a variety of reasons. The principal reasons are listed below.

(1) The variable immersion of the paddle wheel under different ship-loading conditions inhibited use on cargo vessels.

(2) The alternating rise and fall of the wheels at the water level, while the ship was rolling, created a differential thrust or yaw moment, causing the ship to follow an irregular course.

(3) The low speed of paddle wheels required large gear reductions if high-speed prime movers were to be used.

(4) By the time experimenters began systematic model tests and general research in the area of propulsion, the paddle wheel had in most instances been replaced by the screw propeller (as a result, the paddle

wheel has been treated as a specialized item, and published data on design parameters and model experiments are not only very difficult to find but are generally incomplete).

Only a limited amount of significant research has been conducted on paddle wheels, since the early 1900's. A summary and analysis of conventional paddle wheels was published recently by Gerbers, Volpich, and Krappinger.[1,2,3,5,6] They based their study on a series of open-water model tests (there was no ship hull in front of the wheel). Below are two general conclusions that may be drawn from their work:

(1) The propulsive efficiency of a wheel with feathering paddles can be as high as 80 percent. In practice, however, this efficiency falls closer to 50-60 percent, which is what can be expected from well-designed propellers and is much higher than can be expected from water jets. Wheels with fixed radial blades may be approximately 10 percent lower in efficiency than the feathering type.

(2) Efficiency, thrust, and torque generally increase in proportion to rotational speed, up to a slip of approximately 35 percent. At this point, a breakdown in efficiency occurs due, probably, to the losses which accompany entrance and exit of the paddles and to their mutual interference. However, thrust continues to climb with slip.

In recent years, there has been an accelerated development of small high-speed craft for operation in inland waterways. These craft will be able to negotiate the swamps, marshes, and tall grasses that often border these areas, and also operate in open coastal waters. Operational experience in such environments has demonstrated the need for a simple, shallow-draft, weed-free propulsion system for use on such craft. A renewed interest in paddle wheels has developed, as evidenced by the testing currently under way in Europe and the United States.

A few conceptual studies of slow-speed paddle wheels have been conducted.[4,7] Although these paddle wheels have proven quite successful in grass and marsh, they have not been able to generate high speeds in open water, mounted (as they usually were) on craft with displacement-type

hulls. Screw propellers are efficient and provide good maneuverability, but are easily fouled by weeds and require a moderate draft. Axial-flow jet pumps provide good maneuverability and require only a shallow draft, but they are vulnerable to weed ingestion and their low efficiency requires large installed-power levels with the attendant weight, space, and noise penalties.

It seems apparent that a paddle wheel of small diameter, with high rotational speed, can be effectively applied to a planing-hull patrol boat of shallow draft. It is not difficult to imagine a high-speed stern wheel operating entirely within the boundary layer, close behind a planing craft where inflow conditions are constant (perhaps even controllable by transom-mounted flaps). The stern-wheel propulsion device would be of the fixed radial-blade type and would be ventilated at high speeds. Instead of having spokes or support arms, the blades would extend from a large central hub and would be supported by concentric discs or end plates. This configuration is simple and rugged and will resist fouling by weeds. The end discs and the blade ends could be used for support during operation in the land environment.

The disadvantages of the paddle wheel will not apply in this case, since --

(1) A patrol boat will generally be operating near a single loading condition, and variable immersion of the paddle wheel would not present a problem.

(2) The paddle wheel of a patrol boat will be operating in the wake aft of the transom of a planing hull, and the paddle wheel therefore will not experience differential submersion due to roll motion.

(3) Any speed-reduction problem that is likely to arise can be overcome by the application of modern lightweight power-transmission designs.

OBJECTIVES OF THIS PROGRAM

The basic objectives of this program were as follows:

(1) To determine, by means of systematic model experiments, the hydrodynamic characteristics of a series of paddle-wheel propulsive devices with fixed radial blades.

(2) To determine the feasibility of applying the high-speed paddle wheel to a high-speed planing hull of shallow draft.

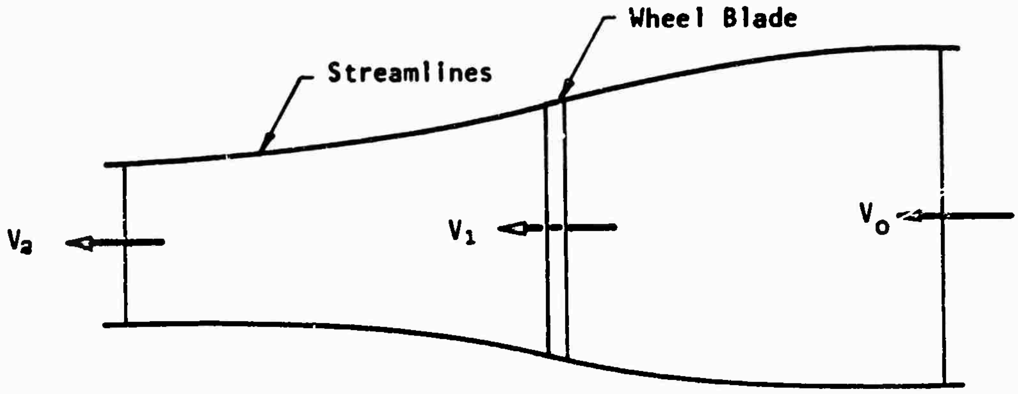
(3) To develop and extend paddle-wheel design parameters for high-speed use.

ANALYSIS

To obtain some paddle-wheel performance data in the high-speed range (i.e., high advance velocity and wheel revolutions), a simplified analysis of the wheel dynamics was performed. Scale-model relationships were derived for the paddle wheel so that the results of the model tests could be related to prototype sizes. The analysis is based on an "ideal" situation and does not take into account such factors as turbulence, cavitation, ventilation, splash, etc. It does, however, yield an upper limit for the expected performance characteristics of the paddle wheel and a means of comparing actual model-wheel operating conditions with the "ideal."

WHEEL DYNAMICS

From momentum theory, thrust can be defined in terms of water inlet and exhaust velocities and wheel geometry (see Nomenclature for definition of symbols).



Utilizing the momentum equation, we write

$$T = \dot{m}\Delta V = \dot{m}(V_2 - V_o) \quad (1)$$

$$= \rho b d V_1 (V_2 - V_o) \quad (2)$$

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But shaft work is represented by

$$TV_1 = V_1\dot{m}(V_2 - V_o)$$

which is equal to the change in the kinetic energy of the fluid, or

$$\tfrac{1}{2}\dot{m}(V_2{}^2 - V_o{}^2) \qquad (3)$$

Therefore

$$V_1 = \frac{V_2{}^2 - V_o{}^2}{2(V_2 - V_o)} = \frac{V_2 + V_o}{2} \qquad (4)$$

Substituting Eq. (4) into Eq. (2), we get

$$T = \rho bd \frac{V_2 + V_o}{2} (V_2 - V_o) = \tfrac{1}{2}\rho bd(V_2{}^2 - V_o{}^2)$$

Rearranging, we have

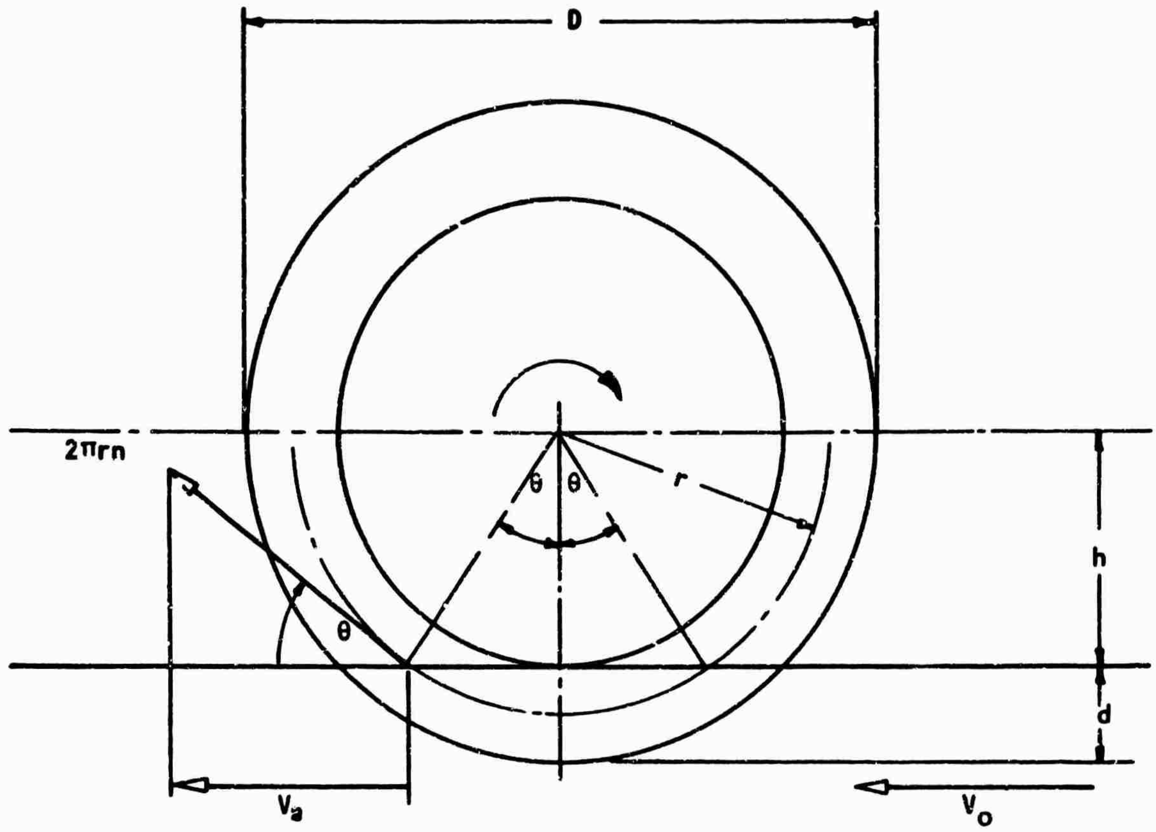
$$V_2 = \left[\frac{2T}{\rho bd} + V_o{}^2\right]^{\frac{1}{2}} \qquad (5)$$

If we assume that the downstream velocity vector of the water leaving the blade is tangent to the blade arc, as shown in the sketch on the next page, we may write the relationship of the wheel rotational speed, the water exhaust velocity, and the angle θ as shown below (Eq. [6]).

$$\begin{aligned} V_2 &= 2\pi rn \cos\theta \\ &= 2\pi hn \end{aligned} \qquad (6)$$

Transposing, we obtain

$$n = \frac{V_2}{2\pi h}$$



A conservative approximation of torque, in terms of thrust, is

$$Q = \frac{Tr}{\cos\theta} = \frac{Tr^2}{h} \tag{7}$$

Solving for efficiency, we write

$$\eta_p = \frac{TV_o}{2\pi nQ} = \left(\frac{V_o}{V_a}\right)\left(\frac{h}{r}\right)^2 \tag{8}$$

It will be noted that efficiency is proportional to the ratio of the inlet and exhaust velocities and is very sensitive to the ratio of the height of the paddle axis to the effective radius.

Although this analysis is, admittedly, rather simplified, it nevertheless serves to indicate that efficient paddle-wheel propulsion systems can be designed within practical limitations, using existing power-transmission equipment (see Appendix A).

SCALE-MODEL RELATIONSHIPS

Scale-model relationships were derived in order to have some rational method of selecting a wheel size and to make possible the correlation of the results with results for prototype wheels and earlier studies.

Since frictional effects are considered small as compared with inertial forces, we choose to scale by Froude Number , Fr , where

$$Fr = \frac{V}{\sqrt{gD}}$$

Let V be the relative velocity between water and blade-tip speed (i.e., blade-tip speed minus advance velocity of vehicle). Then

$$Fr = \frac{\pi nD - V_o}{\sqrt{gD}}$$

Let $\lambda = D_p/D_m$, the scale factor. Then for equal Froude number,

$$\left(\frac{\pi nD - V_o}{\sqrt{gD}}\right)_{model} = \left(\frac{\pi nD - V_o}{\sqrt{gD}}\right)_{prototype} \tag{9}$$

$$\frac{\pi n_m D_m}{\sqrt{D_m}} - \frac{V_{o_m}}{\sqrt{D_m}} = \frac{\pi n_p D_p}{\sqrt{D_p}} - \frac{V_{o_p}}{\sqrt{D_p}}$$

and therefore

$$\pi \left[n_m \sqrt{D_m} - n_p \sqrt{D_p} \right] = V_{om} / \sqrt{D_m} - V_{o_p} / \sqrt{D_p} \tag{10}$$

Or, on substituting the relationship for the scale factor into Eq. (10), we can write

$$\pi \sqrt{D_m} \, (n_m - \sqrt{\lambda}\, n_p) = 1 / \sqrt{D_m} \, (V_{o_m} - V_{o_p} / \sqrt{\lambda}) \tag{11}$$

To fix the model, we choose to make both sides of Eq. (11) equal to zero. Then the linear water speed or advance velocity is

$$V_{o_p} = \sqrt{\lambda}\, V_{o_m} \tag{12}$$

and the rotational speed is

$$n_m = \sqrt{\lambda}\, n_p \tag{13}$$

From dimensional analysis, the thrust forces may be expressed as

$$T_m = \frac{T_p}{\lambda^3} \tag{14}$$

Since $$Q_p = F_p L_p = \lambda^3 F_m \lambda L_m = \lambda^4 Q_m$$

torque may be represented by

$$Q_m = \frac{Q_p}{\lambda^4} \tag{15}$$

and since

$$P_p = \frac{F_p L_p}{T_p} = \frac{\lambda^3 F_m \lambda L_m}{\sqrt{\lambda}\, T_m} = \lambda^{7/2} P_m$$

power can be written

$$P_m = \frac{P_p}{\lambda^{7/2}} \tag{16}$$

Efficiency is expressed as

$$\eta_p = \eta_m \tag{17}$$

A calculation of the forces expected from a scale model are given in Appendix A.

MODEL AND APPARATUS

PADDLE-WHEEL MODEL

On the basis of the scale-model analysis and in consideration of the test facility's limitations, it was decided that the paddle-wheel model should have an outside diameter of 5 inches and be 5-in. wide. The scale model was a radial wheel with fixed paddles and end plates (Fig. 1). Two paddle wheels were constructed. Their dimensions were identical, but one had six blades and the other had twelve blades. To reduce cavitation and entrapped air, holes one-half inch in diameter were drilled in the end plates between the blades. The wheel was driven by a $\frac{1}{2}$-hp d-c motor in a closed-loop servo. The speed of the motor was measured by a d-c tachometer and fed back to the control amplifier. Speeds were set on a ten-turn dial and checked with an electronic strobe light.

The entire wheel, drive, motor, and tachometer assembly was mounted on a three-component balance system. The balance system was set up to measure the torque, thrust, and lift produced by the paddle wheel. Preliminary data showed the lift component to be negligible, and the lift element was therefore removed to reduce vibration and noise in the over-all recording system.

The entire assembly, including paddle wheel, drive, tachometer, torque balance, thrust balances, and the necessary counter-balance weights, was mounted on a base plate. The base plate had screws for leveling, raising, or lowering, and served as a means of clamping the entire assembly into the test section of the water channel (Fig. 2). A height-adjustable, flat-bottomed plate, simulating a boat planing hull, was mounted just forward of the paddle wheel. This plate provided a flow to the wheel similar to that which would appear on a moving boat, and served as the reference line from which paddle immersions were measured.

WATER CHANNEL

Tests were conducted in the Davidson Laboratory's variable-pressure free-surface water channel (Fig. 3). This facility has a 6-ft-long test section 13-in. wide and 13-in. deep, with a 7-in. water depth. The maximum water speed is 18 fps. The water channel can be completely closed and operated at reduced pressures (in which case it would be referred to as a water tunnel), but this was not required for the present study. The photograph shows that the return section and pump are located on the right. The water flows in a clockwise direction up to the contraction nozzle located just forward of the test section. The test section has windows on both sides for almost the entire length. The two hand wheels can be used to tilt the floor of the test section, to reduce the standing waves which develop at certain water velocities.

The paddle wheel, planing hull, and balances were inserted through the top of the channel and positioned midway in the test section. The water, after passing to the rear of the paddle wheel, was collected in the upper right-hand separating chamber. The main stream of water was deflected down into the return section. The upper portion of the separating section skimmed off the turbulent and aerated water and allowed it to settle before it flowed back to the return section.

The various pressure taps and the manometer bank are not shown in the photo. A 4-ft high platform provides a work area and serves as an observation post.

INSTRUMENTATION

Force Balances and Electronic Recording Equipment (Fig. 4)

The force balances are designed around specially machined spring flexures which introduce almost no cross-coupling or hysteresis when properly used. For each force input, the spring flexures allow a given displacement which is sensed and measured by linear variable differential transformers (LVDT).

The output from the torque and thrust balance LVDT's was fed to a Sanborn carrier amplifier (350-1100) and recorder. To reduce distortion and overloading, due to vibration and the impact noise superimposed on the steady-state readings, the carrier amplifiers were set at very low gain. This was done so that the composite signal would be passed without asymmetrical clipping. After the signal was demodulated and fed to the d-c output, it was filtered to remove the unwanted vibration and noise, leaving the steady-state d-c level. This signal was then fed to a Sanborn d-c amplifier (350-1000), where it was amplified to drive an 8-in. Minneapolis-Honeywell Visicorder. Each signal channel was adjusted to give 7-in. chart deflection for full-scale torque and thrust.

The thrust and torque calibrations were fixed by using weights in a line and pulley arrangement to apply a known force to the paddle wheel and blade.

Paddle-Wheel and Water Speed Control

Constant paddle-wheel speed was maintained by means of a tachometer attached to the drive motor shaft. The output of the tachometer was fed to the control amplifier as one of two summing inputs. The other input was from a 10-turn speed-control potentiometer. When this speed-control potentiometer was adjusted, it supplied a fixed voltage reference, unique to that particular speed setting. To balance the amplifier input the tachometer had to be driven to a voltage level very near the speed reference voltage but of opposite sign. When the two voltages were balanced, the wheel speed remained constant even over fairly large increases or decreases in load.

A similar summing input and amplifier arrangement was used for the speed control on the water channel. The drive-motor armature voltage was sampled and summed with the reference from the speed-control potentiometer. For the final control, a General Electric Thymotrol was used to supply armature current. The inertia of the large mass of water, and the fact that only a relatively small amount of energy from the model was available to accelerate the water, combined to keep the channel velocity constant over large changes of model speed.

Water-Channel Speed Measurement

The water velocity was evaluated by measuring the difference in static pressure at the entrance and outlet of the nozzle. The taps in the side of the channel were connected to manometer tubes, calibrated in millimeters of water. Thus,

$$V(\mathrm{ft/sec}) = \frac{0.145}{3.281}\sqrt{h(\mathrm{mm})}$$

based on a contraction ratio of 1:4 in the nozzle. Results obtained with the manometer tubes and static-pressure taps were checked with a Prandtl tube mounted in the test section of the channel, and were found to be valid.

TEST PROGRAM AND TEST PROCEDURE

Four experimental variables were involved in the test program: immersion depth (d), wheel speed (n), water velocity or advance velocity (V_o), and the number of blades on the paddle wheel.

The test points for each variable were --

V_o : 3.6, 4.6, 5.4, and 7.7 fps

d : 0.3, 0.5, and 0.8 in.

N : up to 1600 rpm in increments of 100 rpm

Number of blades: 12 and 6

The wheel was tested for all combinations of the above variables; and the thrust, torque, wheel speed, wheel immersion, and water velocity were recorded.

The test sequence was as follows:

(1) Select a water velocity (V_o).

(2) Select an immersion depth (d).

(3) Vary wheel speed (N), throughout the range and record the thrust, torque , N , and V_o .

(4) Repeat step (3) with a different V_o until the range of V_o is covered.

(5) Repeat steps 1 to 4 with a different d until the range of d is covered.

(6) Repeat steps 1 to 5 with the next model paddle wheel having a different number of blades.

FORMULAS FOR DATA ANALYSIS

From the data obtained in the model tests, various dimensional and non-dimensional parameters were calculated. For convenience, these were programmed to be run on an IBM 360/40 computer. Program and data are given in Appendix B.

The input data consisted of --

Number of blades
Wheel diameter , D (in.)
Blade immersion depth , d (in.)
Ratio of d/D
Advance velocity , V_o (fps)
Wheel speed , N (rpm)
Wheel thrust , T (lbs)
Torque input , Q (ft-lb)

Two similar sets of parameters were calculated for purposes of analysis and comparison with results reported in the literature. These sets are labeled Method 1 and Method 2.

METHOD 1

$$n(\text{rps}) = \frac{N(\text{rpm})}{60}$$

$$h = \frac{D}{2} - d$$

$$\lambda_1 = \frac{12\ V_o}{\pi n D} = \text{advance ratio (\underline{not} the scale factor)}$$

$$K_T = \frac{T(12)^4}{\rho n^2 D^4} = \text{thrust coefficient}$$

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$$K_Q = \frac{Q(12)^5}{\rho n^2 D^5} = \text{torque coefficient}$$

$$Fr = \frac{\pi}{\sqrt{12g}} n \sqrt{D} = \text{Froude number based on wheel speed}$$

$$s_r = (1-\lambda_1) = \text{slip}$$

$$\eta_p = \frac{K_T}{K_Q} \frac{\lambda}{2} = \text{propulsive efficiency}$$

METHOD 2

$$\frac{T}{\rho D^3} (12)^3 = \text{a frequently used thrust parameter}$$

$$\frac{Q}{\rho D^4} (12)^4 = \text{a frequently used thrust parameter}$$

$$V_a = 0.5921\ V_o\ \text{(knots)}$$

$$\frac{V_a}{\sqrt{D/12}} = \text{a frequently used velocity parameter}$$

$$\sqrt{N \frac{D}{12}} = \text{a frequently used velocity parameter}$$

$$N \sqrt{\frac{D}{12}} = \text{a frequently used velocity parameter}$$

$$\eta_p = \frac{T\ V_o}{QN} \frac{5252}{550} = \text{propulsive efficiency}$$

$$s_{r_{eff}} = \frac{n\pi(\frac{D}{2} + h) - 12\ V_o}{n\pi(\frac{D}{2} + h)} = 1 - \frac{12\ V_o}{n\pi(\frac{D}{2} + h)} = \text{effective slip}$$

RESULTS

The preliminary tests showed a high torque input to the wheel, with a corresponding low thrust, which resulted in a low propulsive efficiency. It was believed that there was insufficient venting of the cavity formed between adjacent blades and that an "air pocket" was being formed that prevented the water from filling the cavity. Vent holes 0.5 inch in diameter were therefore drilled into the side plates between adjacent blades. These vent holes insured sufficient ventilation and improved the performance slightly over some ranges of operation.

The test results for the final configuration are presented in graphical form (Figs. 5 to 49). The computer program used to calculate the various dimensional and non-dimensional parameters, and the test data and performance parameters, are given in Appendix B.

The primary results are shown in Figs. 5 to 16 as thrust and torque versus wheel speed, with advance velocity, blade immersion depth, and number of blades as changing parameters. Comparison of Fig. 5 with 6, 7 with 8, and 9 with 10 (these are plots of thrust versus wheel speed for three different immersion depths) indicates that the six-bladed wheel usually generates more thrust than the twelve-bladed wheel. This can also be seen quite clearly in Figs. 11 to 13, which are composites of Figs. 5 to 10. A similar comparison of Fig. 14 with 15, 16 with 17, and 18 with 19 shows that the torque is also larger for the six-bladed wheel.

An interesting feature that should be noted on almost all the figures is the apparent break in the thrust and torque curves which occurs at high advance velocities.

Figures 20 to 25 are plots of thrust versus effective slip for various advance velocities, blade immersion depths, and number of wheel blades. Here, also, thrust can be seen to increase smoothly with increasing slip. At the higher advance velocity, however, there is a thrust "breakdown" which occurs at about 40-percent slip. This breakdown appears to occur

over a span of about 10 percent in slip, after which the thrust again continues to increase with increasing slip.

Similar breakdown phenomena have been reported in the literature,[1,2] but no satisfactory explanation of why this phenomena occurs is available. By comparing Fig. 20 with 21, 22 with 23, and 24 with 25, it can readily be seen that this phenomenon is more pronounced in the case of the six-bladed wheel.

It can also be noted, in Figs. 20 to 25, that the thrust curves do not go to zero for zero effective slip. This is because of the "form" drag of the wheel itself, and other losses. Comparison of the curves for different blade immersions shows that for smaller immersions (i.e. , d = 0.5 , 0.3) the thrust at zero slip more closely approaches zero, which is to be expected since there is less wheel in the water and hence less loss.

Figures 26 to 31 are plots of propulsive efficiency versus wheel speed at various advance velocities, blade immersion depths, and number of wheel blades. Figures 32 to 37 are plots of the same data versus effective slip. Comparison of the figures shows that the six-bladed wheel also has a higher efficiency than the twelve-bladed wheel, with the maximum efficiency occurring in the vicinity of 30- to 40-percent slip. The maximum value of propulsive efficiency achieved is 41 percent, which is in agreement with some of the more recent literature,[10] but considerably lower than that presented in some earlier reports.[1,2] The efficiency curve is very "peaky"; that is, the high values of efficiency occur over a rather narrow range, then fall off sharply. The twelve-bladed wheel usually develops its maximum efficiency at a slip value that is somewhat higher than that for the six-bladed wheel.

Figures 26 to 37 show that the peak efficiencies increase with increasing immersion. This result is not what would normally be expected, and a completely satisfactory explanation is not available. A partial explanation may be that the "form" drag of the wheel does not vary linearly with immersion depth and may affect the ratio of net thrust to input torque in such a manner as to produce a maximum efficiency for some value of immersion depth above which the efficiency may again decrease. It is also of interest to note that all the efficiency curves, regardless

of blade immersion depth or number of wheel blades, join to form a single line at slip values above 70 percent.

Figures 38 to 49 present the test data as functions of torque coefficient and thrust coefficient, common parameters utilized by naval architects.

PREDICTION OF PROTOTYPE PERFORMANCE

If we choose as our prototype a small "jeep size" vehicle having a planing type hull, we can estimate quite accurately the power required to propel it at any given speed. The model paddle wheel test results can then be scaled up to match the vehicle.

Assume that the prototype characteristics are:

Overall length = 18 ft
Width (beam) = 5 ft
Gross weight = 4000 lb
Center of gravity location = 7.5 ft from bow
Deadrise = 15 degrees
Hull type = planing

The Davidson Laboratory "SPDBOT Program"[11] will then predict the drag versus speed curve shown in Figure 50. As a compromise between wheel size and efficiency, we have selected a 4 ft diameter wheel, 4 ft wide, with six paddles.

From dimensional analysis

$$\lambda = \frac{D_p}{D_m} = \frac{4}{5.0/12} = 9.6$$

$$N_p = \frac{1}{\sqrt{\lambda}} N_m = 0.323\ N_m \tag{18}$$

$$T_p = \lambda^3\ T_m = 884\ T_m \tag{19}$$

$$V_{o_p} = \sqrt{\lambda}\ V_{o_m} = 3.095\ V_{o_m} \tag{20}$$

$$P_p = \frac{\lambda^{7/2}}{5252} Q_m N_m = 0.0436\ Q_m(\text{in-lb})N_m(\text{rpm})) \tag{21}$$

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For ease of discussion, we shall scale down the full-scale drag versus speed curve of the prototype from Figure 50 to match that of the model test results. To do this, we divide the drag values by λ^3 and the speed values by $\sqrt{\lambda}$. We now have a curve of drag (or thrust) versus speed which we can match with experimental test data from the 5 inch model paddle wheel, Figure 51. In Figure 51, lines of thrust versus advance velocity for constant wheel speed have been added to illustrate the reserve capability of the wheel.

By determining the required thrust at 3.6, 4.6, 5.4, and 7.7 fps from Figure 51, we can determine from figures 5, 14, and 26, the required wheel operating conditions (T_m, N_m, Q_m, η_p and horsepower) to match the prototype requirements. Substituting these values of model wheel operating conditions into equations 18, 19, 20 and 21 gives us the operating conditions of the prototype vehicle and wheel.

From Figure 51 we see that the model operating conditions which match the model advance velocity of 7.7 fps are

$$T_m = 0.660 \text{ lb}$$

$$N_m = 620 \text{ rpm}$$

$$V_{o_m} = 7.7 \text{ fps}$$

$$Q_m = 3.40 \text{ in-lb}$$

$$\eta_p = 26 \text{ percent}$$

Substituting these values into equations 18, 19, 20 and 21 yields the following prototype conditions:

$$N_p = 200 \text{ rpm}$$

$$T_p = 5881 \text{ lb}$$

$$V_{o_p} = 14.1 \text{ knots} = 16.3 \text{ miles/hour}$$

Required horsepower shaft = 92 hp

These values are well within the realm of practicality for a usable reconnaissance vehicle.

From the dynamic analysis on page 7, the following equation was generated for the thrust of a paddle wheel.

$$T = \frac{1}{2} \rho b d(V_a{}^2 - V_o{}^2) = \frac{1}{2} \rho b d \,[(2\pi h n)^2 - V_o{}^2]$$

If we take the same data from page 26 ($d = 0.8$ in., $V_o = 7.7$ fps, $b = 5.0$ in., and $n = 10.3$ and 16.7 rps), we get

$$T = 0.0269\,[84.2-59.3] = 0.67 \text{ lb} \quad \text{for} \quad n = 10.3$$

and

$$T = 0.0269\,[221-59.3] = 4.35 \text{ lb} \quad \text{for} \quad n = 16.7$$

Under these operating conditions, however, our model generated a thrust of 0.665 lb and 1.0 lb which indicates that the simplified analysis gives good agreement (0.665 lb vs. 0.67 lb) provided the wheel speed is sufficiently slow so that cavitation and/or ventilation does not occur. When the wheel speed is sufficiently high to cavitate and/or ventilate, the simplified analysis predicts results which are quite optimistic (4.35 lb vs. 1.00 lb).

The measured test data does not extend above a prototype speed of 16.3 mph for the vehicle size chosen. However, it can be seen in Figure 50 that the drag curve is fairly flat at the speeds near to 42 fps (29 mph). It is therefore reasonable to assume that the paddle wheel will be able to provide the required thrust for speeds near 30 mph with somewhat greater horsepower. Figure 52 is a simplified concept drawing of a possible configuration of a high speed amphibious reconnaissance vehicle utilizing a paddle wheel propulsion system.

CONCLUSIONS

(1) There is a considerable amount of mechanical vibration in the system, because of the impact loading of the paddle wheel. This must be filtered out. Special procedures must be employed, when using filters, to eliminate the noise in the thrust and torque signals and ensure that asymmetrical "clipping" of the signals in the amplifiers does not occur.

(2) The six-bladed wheel generates more thrust than the twelve-bladed wheel.

(3) The six-bladed wheel is significantly more efficient than the twelve-bladed wheel.

(4) Maximum efficiency occurs at about 30- to 40-percent slip for the six-bladed wheel and at about 50-percent slip for the twelve-bladed wheel.

(5) Thrust and efficiency increase with increasing immersion depth, within the range of immersions tested (d/D = 0.06 to 0.16).

(6) A maximum propulsive efficiency of 41 percent was obtained with the six-bladed wheel.

(7) There is a break in the thrust curves, in the region of 30- to 50-percent slip, which spans about 10-percent slip (Figs. 19 to 24). It is most noticeable on the six-bladed wheel and occurs at high advance velocities. A satisfactory explanation has not been found. However, it is felt that the break may be due to some type of flow instability or wave interference.

(8) There appears to be some type of flow phenomenon which more seriously affects a wheel of small diameter than a wheel of large diameter. This is especially noticeable in comparing the efficiency curves with those obtained by other experimenters who used a wheel of larger diameter.[1,2,10] The

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curve for the small wheel may have the same peak value of efficiency, but it occurs over a narrow range and falls off sharply.

(9) Because of the relatively high peak efficiency found in this series of experiments, the application of a high-speed paddle wheel to a planing hull of shallow draft is deemed feasible.

RECOMMENDATIONS

A design study of a small, high-speed vessel propelled by a paddle wheel should be undertaken. On the basis of the results of this study, a small prototype could be built, instrumented, and tested.

To avoid possible deficiencies in any full-scale design based on the test model, it is recommended that any future experiments and tests be performed on a wheel of larger diameter, since scale distortions were evident with a scale factor of about 8.5:1. A scale factor of 3:1 or 2:1 would be most desirable.

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Appendix A
A CALCULATION OF THE FORCES EXPECTED FROM A SCALE MODEL

For a 30-knot craft with a gross weight of 12,000 to 15,000 lb, we can determine the characteristics for one unit of a twin-stern wheel-propulsion system by using the equations derived in the dynamic analysis of a paddle wheel. The required thrust is known because the hull shape, drag coefficient, and required vehicle speed are known, or can be estimated accurately.

$$T = 1200 \text{ lb/unit}$$

$$V_o = 30 \text{ knots} = 50.7 \text{ ft/sec}$$

Choosing the dimensions

$$D = 3.5 \text{ ft} , \; d = 0.5 \text{ ft} , \; h = 1.25 \text{ ft} , \; r = 1.5 \text{ ft} , \; b = 3.5 \text{ ft}$$

for the wheel, then

$$V_a = \left[\frac{2T}{(b)(d)\rho} + V_o^2\right]^{\frac{1}{2}} = \left[\frac{2(1200)}{(3.5)(0.5)(2)} + (50.7)^2\right]^{\frac{1}{2}} = 56.6 \text{ ft/sec}$$

$$n = \frac{V_a}{2\pi h} = \frac{56.6}{2\pi(1.25)} = 7.20 \text{ rps} \quad ; \quad N = (7.20)(60) = 432 \text{ rpm}$$

$$Q = \frac{Tr^2}{h} = \frac{(1200)(1.5)^2}{1.25} = 2160 \text{ ft-lb}$$

$$\text{shp} = \frac{QN}{5252} = \frac{(2160)(432)}{5252} = 177/\text{unit}$$

$$\text{ehp} = \frac{TV_o}{550} = \frac{(1200)(50.7)}{550} = 110.0$$

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$$\eta_p = \frac{ehp}{shp} = \frac{110}{177} = 0.62$$

The size of the paddle wheel and the size of the power units are well within practical limitations.

TO SCALE THE EXAMPLE, USING A MODEL PADDLE WHEEL

Prototype characteristics are as follows:

$T = 1200$ lb

$V_o = 30$ knots $= 50.7$ fps

$D = 3.5$ ft , $b = 3.5$ ft , $h = 1.25$ ft

$V_a = 56.6$ fps

$N = 432$ rpm

$Q = 2160$ ft/lb

$shp = 177$

$ehp = 110$

$\eta_p = 62$

Using a 5.0 by 5.0 in. model, we obtain

$$\lambda = \frac{42}{5.0} = 8.4$$

$$N_m = \sqrt{8.4}\,(432) = 1250 \text{ rpm}$$

$$T_m = \frac{1200}{(8.4)^3} = 2.03 \text{ lb}$$

$$Q_m = \frac{2160}{(8.4)^4} = 0.434 \text{ ft-lb} = 5.22 \text{ in.-lb}$$

$$P_m = \frac{177}{(8.4)^{7/2}} = 0.1028 \text{ shp}$$

$$\eta_m = 0.62$$

$$V_{o_m} = \frac{50.7}{\sqrt{8.4}} = 17.5 \text{ fps}$$

$$V_{a_m} = \frac{56.6}{\sqrt{8.4}} = 19.5 \text{ fps}$$

SPECIAL CASE (MAXIMUM ACCELERATION OR THRUST) WHEN $V_o = 0$ and N = MAXIMUM FOR d/D = 0.143

$$V_a = \left[\frac{2T}{bd\rho} + V_o^2\right]^{\frac{1}{2}} = 2\pi hn$$

Therefore $$T = 2\pi^2 h^2 n^2 bd\rho$$

when $V_o = 0$; and for $\lambda = 8.4$,

$$T = \frac{2(3.1416)^2(1.786)^2(5.0)(0.714)(62)(20.7)^2}{32.2 \times 12 \times 1728}$$

$$= 8.95 \text{ lb}$$

$$Q = \frac{8.95(2.143)^2}{1.786} = 23.1 \text{ in.-lb}$$

$$\text{shp} = \frac{2\pi(20.7)(23.1)}{550\times12} = 0.455$$

These calculated values of thrust and torque will, however, be unattainable, because of the ventilation and/or cavitation of the paddle wheel. They do, however, give an upper limit to the forces that can be expected.

Appendix B

DATA REDUCTION PROGRAM AND LISTING OF DATA OUTPUT

```
CODBAT.BPT          F40       V22       2-JUN-70          10:52    PAGE 1

                DIMENSION V2(500),D(500),DS(500),DL(500),N(500),T(500),Q(500)
                INTEGER B(500),X
                REAL L(500)
                DO 1 I=1,500
                READ(5,3)B(I),D(I),DL(I),DS(I),V2(I),N(I),T(I),Q(I),L(I)
                IF(B(I).EQ.-1) GO TO 2
                II=I
              3 FORMAT(I2,4(F6.3),I5,3(F6.3))
              1 CONTINUE
              2 I=1
             11 X=2
              6 WRITE(6,4)B(I),D(I),DS(I),DL(I),V2(I)
              4 FORMAT('1','THEMIS PROJECT NUMBER 1',39X,'HIGH SPEED PADDLE-WHEEL'
               2,32X,'OCTOBER 1968'///
               2' ','NUMBER OF BLADES=',I3,14X,'D=',F6.4,17X,'LITTLE D/D=',F6.4,
               217X,'LITTLE D=',F6.3,12X,'V2=',F6.3///
               2' ','METHOD I'/
               2' ','RPM',5X,'LITTLE N',4X,'LITTLE H',4X,'LAMBDA SUB 1',4X,'KT',
               26X,'KL',6X,'KQ',6X,'FROUDE NO.',4X,'SLIP',3X,'ETA',7X,'T',7X,
               2'L',7X,'Q'/)
              7 IF(B(I).NE.B(I+1).OR.D(I).NE.D(I+1).OR.DS(I).NE.DS(I+1).OR.DL(I).
               2NE.DL(I+1).OR.V2(I).NE.V2(I+1)) GO TO 5
                D(I)=D(I)/12
                FN=N(I)
                F1=FN/60.
                F2=D(I)/2.-DL(I)
                F3=(12*V2(I))/(3.1415*F1*D(I))
                F4=(T(I)*12**4)/(1.937*F1**2*D(I)**4)
                F5=(L(I)*12**4)/(1.937*F1**2*D(I)**4)
                F6=(Q(I)*12**5)/(1.937*F1**2*D(I)**5)
                F7=(3.1415*F1*SQRT(D(I)/(12*32.2)))
                F8=1-F3
                F9=0.
                IF(F6.NE.0.)F9=(F4/F6)*(F3/2)
                WRITE(6,8)N(I),F1,F2,F3,F4,F5,F6,F7,F8,F9,T(I),L(I),Q(I)
              8 FORMAT(' ',I4,3X,F8.4,5X,F7.4,8X,F7.4,4X,F7.4,2(1X,F7.4),4X,F7.4,
               25X,F7.4,4(1X,F7.4))
                I=I+1
                X=X+1
                IF(I.LT.II)GO TO 7
              5 D(I)=D(I)/12
                FN=N(I)
                F1=FN/60.
                F2=D(I)/2.-DL(I)
                F3=(12*V2(I))/(3.1415*F1*D(I))
                F4=(T(I)*12**4)/(1.937*F1**2*D(I)**4)
                F5=(L(I)*12**4)/(1.937*F1**2*D(I)**4)
                F6=(Q(I)*12**5)/(1.937*F1**2*D(I)**5)
                F7=(3.1415*F1*SQRT(D(I)/(12*32.2)))
                F8=1-F3
                F9=0.
                IF(F6.NE.0.)F9=(F4/F6)*(F3/2)
                WRITE(6,9)N(I),F1,F2,F3,F4,F5,F6,F7,F8,F9,T(I),L(I),Q(I)
```

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OOBAT.PPT        F40      V22      2-JUN-70         10(51    PAGE 2

        000622        9 FORMAT(' ',I4,3X,F8.4,5X,F7.4,8X,F7.4,4X,F7.4,2(1X,F7.4),4X,F7.4,
                       25X,F7.4,4(1X,F7.4)///
                       2' ','METHOD II(VCLPICH)'/
                       2' ','RPM',3X,'(T*12**3)/(RHO*D**3)',3X,'(Q*12**4)/(RHO*D**4)',5X,
                       2'VA',7X,'VA/SQRT(D/12)',4X,'SQRT(ND/12)',4X,'NSQRT(D/12)',5X,
                       2'ETA',3X,'EFFECTIVE SLIP'/)
        000732          I=I-X
        000734       20 IF(B(I).NE.B(I+1).OR.D(I).NE.D(I+1).OR.DS(I).NE.DS(I+1).OR.DL(I).
                       2NE.DL(I+1).OR.V0(I).NE.V0(I+1)) GO TO 10
        000766          H1=(T(I)*12**3)/(1.937*D(I)**3)
        001001          H2=(Q(I)*12**4)/(1.937*D(I)**4)
        001014          H3=.5921*V0(I)
        001022          H4=H3/SQRT(D(I)/12)
        001031          H5=SQRT(N(I)*D(I)/12)
        001043          H6=N(I)*SQRT(D(I)/12)
        001057          H7=0
        001062          IF(Q(I).NE.0)H7=(T(I)*V0(I)*5252)/(Q(I)*N(I)*550)
        001076          FN=N(I)
        001103          F1=FN/60.
        001106          H8=1-((12*V0(I))/((F1*3.1415)*(D(I)/2*F2)))
        001122          WRITE(6,22)N(I),H1,H2,H3,H4,H5,H6,H7,H8
        001137       22 FORMAT(' ',I4,6X,F9.4,14X,F9.4,7X,F9.4,5X,F9.4,6X,F9.4,6X,
                       2F9.4,3X,F9.4,3X,F8.4)
        001161          I=I+1
        001162          IF(I.LT.II)GO TO 20
        001165       10 H1=(T(I)*12**3)/(1.937*D(I)**3)
        001202          H2=(Q(I)*12**4)/(1.937*D(I)**4)
        001213          H3=.5921*V0(I)
        001217          H4=H3/SQRT(D(I)/12)
        001234          H5=SQRT(N(I)*D(I)/12)
        001242          H6=N(I)*SQRT(D(I)/12)
        001256          H7=0
        001257          IF(Q(I).NE.0)H7=(T(I)*V0(I)*5252)/(Q(I)*N(I)*550)
        001275          FN=N(I)
        001302          F1=FN/60.
        001305          H8=1-((12*V0(I))/((F1*3.1415)*(D(I)/2*F2)))
        001321          WRITE(6,23)N(I),H1,H2,H3,H4,H5,H6,H7,H8
        001336       23 FORMAT(' ',I4,6X,F9.4,14X,F9.4,7X,F9.4,5X,F9.4,6X,F9.4,6X,
                       2F9.4,3X,F9.4,3X,F8.4)
        001360          I=I+1
        001361          IF(I.LT.II)GO TO 11
        001364     1000 STOP
        001365          END

CONSTANTS

0        204620222020    1        206740202220    2        202622071260    3        201757676355    4        211602314031
5        200457117354    6        215512220220

SUBPROGRAMS

FORSE.   JOBFF    INTO.    INTI.    FLOUT.   FLIRT.   FLOAT    SQRT     EXIT
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OQBAT.BPT        F40     V20     2-JUN-78        10:51   PAGE 3

SCALARS

I       1401            II      1402            X       1403            FN      1404            F1      1405
F2      1406            F3      1407            F4      1410            F5      1411            F6      1412
F7      1413            F8      1414            F9      1415            H1      1416            H2      1417
H3      1420            H4      1421            H5      1422            H6      1423            H7      1424
H8      1425

ARRAYS

V2      1426            U       2412            DS      3376            DL      4362            N       5346
T       6332            Q       7316            S       10302           L       11266

MAIN.   ERRORS DETECTED: 0

3K CORE USED
```

THEMIS PROJECT NUMBER 1 HIGH SPEED PADDLEWHEEL OCTOBER 1960

NUMBER OF BLADES= 12 D=5.0000 LITTLE D/D=0.0600 LITTLE D= 0.300 VB= 4.600

METHOD I

RPM	LITTLE N	LITTLE H	LAMBDA SUB 1	KT	KL	KQ	FROUDE NO.	SLIP	ETA	T	L	Q
1615	26.9167	2.2000	0.1376	0.0146	0.0000	0.0094	9.6109	0.8694	0.1010	0.6170	0.0000	0.1640
1470	24.5000	2.2000	0.1434	0.0154	0.0000	0.0104	8.7553	0.8566	0.1050	0.5390	0.0000	0.1522
1340	22.3333	2.2000	0.1574	0.0172	0.0000	0.0121	7.9810	0.8426	0.1119	0.5020	0.0000	0.1470
1200	20.0000	2.2000	0.1757	0.0184	0.0000	0.0131	7.1472	0.8243	0.1236	0.4290	0.0000	0.1271
1040	17.3333	2.2000	0.2027	0.0207	0.0000	0.0154	6.1942	0.7973	0.1359	0.3630	0.0000	0.1120
870	14.5000	2.2000	0.2424	0.0249	0.0000	0.0193	5.1817	0.7576	0.1566	0.3060	0.0000	0.0907
690	11.5000	2.2000	0.3256	0.0322	0.0000	0.0294	4.1096	0.6944	0.1570	0.2330	0.0000	0.0945
515	8.5833	2.2000	0.4094	0.0353	0.0000	0.0454	3.0673	0.5986	0.1594	0.1520	0.0000	0.0813
339	5.6500	2.2000	0.6222	0.0327	0.0000	0.0744	2.0191	0.3780	0.1369	0.0610	0.0000	0.0570
170	2.8333	2.2000	1.2433	-0.0789	0.0000	0.0481	1.0125	-0.2403	-1.2205	-0.0370	0.0000	0.0090
115	1.9167	2.2000	1.8335	-0.5129	0.0000	-0.1175	0.6849	-0.8335	4.0017	-0.1100	0.0000	-0.0105

METHOD II(VOLPICH)

RPM	(T*12**3)/(RHO*D**3)	(Q*12**4)/(RHO*D**4)	VA	VA/SQRT(D/12)	SQRT(ND/12)	NSQRT(D/'	ETA	EFFECTIVE SLIP
1615	4.4734	2.8233	2.7237	4.2195	25.9406	1042.478	0.1010	0.8611
1470	3.8467	2.6078	2.7237	4.2195	24.7487	948.0004	0.1050	0.8474
1340	3.5027	2.5179	2.7237	4.2195	23.6291	864.9663	0.1119	0.8326
1200	3.0617	2.1767	2.7237	4.2195	22.3607	774.5967	0.1236	0.8131
1040	2.5927	1.9326	2.7237	4.2195	20.8167	671.3171	0.1359	0.7843
870	2.1839	1.6900	2.7237	4.2195	19.0394	561.5026	0.1566	0.7482
690	1.6629	1.5186	2.7237	4.2195	16.9558	445.3931	0.1570	0.6749
515	1.0848	1.3931	2.7237	4.2195	14.6487	332.4311	0.1594	0.5644
339	0.4353	0.9892	2.7237	4.2195	11.8849	218.8236	0.1369	0.3303
170	-0.2641	0.1342	2.7237	4.2195	8.4163	109.7345	-1.2205	-0.3195
115	-0.7350	-2.1798	2.7237	4.2195	6.9222	74.2322	4.0015	-0.9586

THEMIS PROJECT NUMBER 1 HIGH SPEED PADDLEWHEEL OCTOBER 1968

NUMBER OF BLADES= 12 C=5,2822 LITTLE D/D=0,0000 LITTLE D= 0,300 VB= 9,400

METHOD I

RPM	LITTLE N	LITTLE H	LAMBDA SUB 1	KT	KL	KQ	FROUDE NO,	SLIP	ETA	T	L	Q
1610	26,8333	2,2000	0,1537	0,0236	0,0006	0,0163	9,5091	0,8463	0,1110	0,9920	0,0000	0,2802
1480	24,6667	2,2000	0,1672	0,0255	0,0006	0,0180	8,8140	0,8328	0,1135	0,9060	0,0000	0,2702
1360	22,6667	2,2000	0,1822	0,0253	0,0000	0,0191	8,1881	0,8180	0,1207	0,7680	0,0000	0,2300
1180	19,6667	2,2000	0,2298	0,0287	0,0000	0,0221	7,2286	0,7902	0,1382	0,6490	0,0000	0,2002
1030	17,1667	2,2000	0,2423	0,0306	0,0000	0,0249	6,1346	0,7597	0,1470	0,5270	0,0050	0,1705
880	14,6667	2,2000	0,2813	0,0331	0,0000	0,0306	5,2413	0,7187	0,1522	0,4160	0,0000	0,1602
720	11,6667	2,2000	0,3536	0,0376	0,0000	0,0404	4,1692	0,6464	0,1644	0,2990	0,0000	0,1330
515	8,5833	2,2000	0,4806	0,0370	0,0000	0,0615	3,0673	0,5194	0,1444	0,1590	0,0000	0,1102
340	5,6667	2,2000	0,7252	0,0197	0,0000	0,0706	2,0250	0,2720	0,1017	0,0370	0,0000	0,0552
170	2,8333	2,2000	1,4562	-0,3926	0,0000	-0,0401	1,0125	-0,4560	7,1253	-0,1840	0,0000	-0,0070

METHOD II(VOLPICH)

RPM	(T*12**3)/(RHO*D**3)	(Q*12**4)/(RHO*D**4)	VA	VA/SQRT(D/12)	SQRT(ND/12)	NSQRT(D/12)	ETA	EFFECTIVE SLIP
1610	7,0797	4,9216	3,1973	4,9533	25,9605	1039,2985	0,1110	0,8344
1480	6,4459	4,7663	3,1973	4,9533	24,0328	955,3359	0,1134	0,8221
1360	5,4240	4,2920	3,1973	4,9533	23,0848	877,8762	0,1207	0,8064
1180	4,6313	3,5655	3,1973	4,9533	22,1734	761,6867	0,1382	0,7768
1030	3,7411	3,2574	3,1973	4,9533	20,7163	664,8621	0,1470	0,7443
880	2,9589	2,7434	3,1973	4,9533	19,1485	568,0376	0,1322	0,7080
720	2,1339	2,2923	3,1973	4,9533	17,0783	451,8481	0,1640	0,6239
515	1,1343	1,8834	3,1973	4,9533	14,6487	332,4311	0,1444	0,4887
340	0,2641	0,9449	3,1973	4,9533	11,9824	219,4691	0,1017	0,2299
170	-1,3132	-2,1342	3,1973	4,9533	8,4163	109,7345	7,1249	-0,5490

THEMIS PROJECT NUMBER 1 HIGH SPEED PADDLEWHEEL OCTOBER 1968

NUMBER OF BLADES= 12 C=9,2000 LITTLE D/D=0,0000 LITTLE R= 0,300 V0= 7,700

METHOD I

RPM	LITTLE N	LITTLE H	LAMBDA SUB 1	KT	KL	KQ	FROUDE NO.	SLIP	ETA	T	L	Q
1420	23,3333	2,2222	2,2521	0,2328	0,2200	0,0301	0,3384	0,7479	0,1290	0,9000	0,0000	0,3990
1352	22,5722	2,2222	2,2614	0,2315	0,2200	0,0286	8,0420	0,7386	0,1442	0,9310	0,0000	0,3510
1132	19,6667	2,2222	2,2991	0,2325	0,2200	0,2329	7,0200	0,7029	0,1479	0,7350	0,0000	0,3097
1042	17,3333	2,2222	2,3394	0,0335	0,0200	0,2361	6,1942	0,6603	0,1494	0,5002	0,0000	0,2702
872	14,5722	2,2222	2,4257	0,0369	0,0200	0,0467	5,1017	0,5943	0,1603	0,4532	0,0000	0,2390
682	11,3333	2,2222	2,5192	0,0523	0,2002	0,0672	4,0521	0,4020	0,2219	0,1920	0,0000	0,2100
512	8,3222	2,2222	2,6921	0,0327	0,0200	0,2507	3,2379	0,3079	0,1922	0,1352	0,0000	0,1023
345	5,7522	2,2222	1,2231	-0,0471	0,2222	0,2176	2,0540	-2,2231	-1,7314	-0,2910	0,0000	0,0190
262	4,3333	2,2222	1,3575	-2,1943	0,0200	-0,0115	1,5400	-0,3575	11,4742	-0,2130	0,0000	-0,0052
925	15,2833	2,2222	2,3970	0,0347	0,2200	0,0469	5,3021	2,6100	0,1623	0,9140	0,0000	0,2572
1092	18,1667	2,2222	2,3230	0,2337	0,0200	0,0372	6,4922	0,6762	0,1470	0,6490	0,0000	0,2967

METHOD II(VOLPICH)

RPM	(T*12**3)/(RHO*D**3)	(Q*12**4)/(RHO*D**4)	VA	VA/SQRT(D/12)	SQRT(ND/12)	NSQRT(D/...)	ETA	EFFECTIVE SLIP
1472	6,9941	6,5342	4,5592	7,2630	24,1523	983,6941	0,1290	0,7310
1352	6,6444	6,2249	4,5592	7,2630	23,7171	871,4212	0,1442	0,7219
1182	5,2456	5,3255	4,5592	7,2630	22,1736	761,0007	0,1479	0,6010
1242	4,1954	4,7662	4,5592	7,2630	[illegible]	[illegible]	0,1494	0,6390
872	3,2334	4,2910	4,5592	7,2630	[illegible]	561,5026	0,1443	0,5404
682	2,7975	3,5972	4,5592	7,2630	16,0329	430,9351	0,2010	0,4470
512	2,9435	1,7528	4,5592	7,2630	14,9774	329,2030	0,1902	0,2030
345	-0,6494	0,2695	4,5592	7,2630	11,9896	222,6963	-1,2314	-0,4004
252	-1,5221	-0,6679	4,5592	7,2630	10,0003	167,0293	11,4730	-0,4442
925	3,6683	4,4263	4,5592	7,2630	19,4106	504,1752	0,1623	0,5051
1090	4,6318	5,0814	4,5592	7,2630	21,3112	703,5920	0,1470	0,6555

THEMIS PROJECT NUMBER 1 HIGH SPEED PADDLEWHEEL OCTOBER 1960

NUMBER OF BLADES= 12 J=5,2820 LITTLE U/D=0,1000 LITTLE D= 0,500 V0= 4,000

METHOD I

RPM	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KQ	FROUDE NO,	SLIP	ETA	T	L	Q
1542	25,6667	2,2200	0,1369	0,0213	0,0000	0,0154	9,1722	0.0631	0.0949	0,0210	0.0000	0,2407
1492	24,6667	2,2202	0,1425	0,0207	0,0007	0,0149	8,8140	0.0575	0.0909	0,7290	0.0000	0,2203
1342	22,3333	2,2222	0,1574	0,0236	0,0000	0,0164	7,9010	0.0426	0.1090	0,6060	0.0000	0,2047
1262	21,0200	2,2202	0,1673	0,0233	0,0000	0,0174	7,5049	0.0327	0.1123	0,6010	0.0000	0,1063
1132	18,8333	2,2222	0,1866	0,0254	0,0000	0,0231	6,7332	0.0134	0.1182	0,5270	0.0000	0,1732
972	16,1667	2,2220	0,2174	0,0281	0,0200	0,0244	5,7773	0,7026	0.1295	0,4290	0.0000	0,1540
853	14,1667	2,2220	0,2491	0,0317	0,0000	0,0250	5,0626	0,7919	0.1526	0,3722	0.0000	0,1240
762	12,6667	2,2222	0,2774	0,0331	0,0000	0,0265	4,5265	0,7226	0.1576	0,2020	0.0000	0,1034
612	10,1667	2,2222	0,3457	0,0365	0,0000	0,0397	3,6331	0.6543	0.1614	0,2200	0.0000	0,0902
425	7,0833	2,2200	0,4961	0,0335	0,0000	0,0045	2,5313	0.5039	0.1206	0,0900	0.0000	0,0700
213	3,5502	2,2220	0,9699	0,0220	0,0020	0,0514	1,2600	0.0101	0.0080	0,0000	0.0000	0,0150
125	2,0833	2,0000	1,6866	-0,0394	0,0000	0,0000	0,7445	-0.6066	0.0000	-0,0000	0.0000	0,0000

METHOD II(VOLPICH)

RPM	(T*12**3)/(RHO*D**3)	(Q*12**4)/(RHO*D**4)	VA	VA/SQRT(D/12)	SQRT(ND/12)	NSQRT(D/12)	ETA	EFFECTIVE SLIP
1542	5,8593	4,2264	2,7237	4,2195	25,3311	994.0057	0,0949	0,0479
1488	5,2456	3,7760	2,7237	4,2195	24,0320	955.3359	0,0909	0,0417
1342	4.8959	3,5270	2,7237	4,2195	23,6291	864.9663	0,1090	0,0252
1262	4,2921	3,1916	2,7237	4,2195	22,9129	813.3265	0,1123	0,0141
1132	3,7612	2,9675	2,7237	4,2195	21,6907	729.4119	0,1182	0,7927
972	3,2417	2,6522	2,7237	4,2195	20,1839	626.1323	0,1259	0,7505
852	2.6549	2,1592	2,7237	4.2195	18,8193	548.6726	0,1526	0,7244
762	2,212	1,7714	2,7237	4,2195	17,7951	490.5779	0,1576	0,6917
612	1,5721	1,6814	2,7237	4,2195	15,9426	393.7533	0,1614	0,6159
425	0,6794	1,3489	2,7237	4,2195	13,3273	274.3363	0,1206	0,4487
213	0,2287	0,2695	2,7237	4,2195	9,4207	137.4929	0,0000	-0,0999
125	-0,6138	0,0223	2,7237	4,2195	7,2169	80.6072	0,0000	-0,0743

THEMIS PROJECT NUMBER 1 HIGH SPEED PADDLEWHEEL OCTOBER 1968

NUMBER OF BLADES= 12 D=5,0000 LITTLE D/D=0,1000 LITTLE D= 0,500 Y0= 5,400

METHOD I

RPM	LITTLE N	LITTLE H	LAMBDA SUB 1	KT	KL	KG	FROUDE NO,	SLIP	ETA	T	L	Q
1522	25,3333	2,2222	0,1628	0,4245	0,0000	0,0195	9,0531	0,8372	0,1037	0,9310	0,0000	0,3049
1422	23,6667	2,2222	0,1743	0,4277	0,0000	0,0229	8,4575	0,8257	0,1099	0,9000	0,0000	0,2992
1312	21,8333	2,2222	0,1890	0,4324	0,0000	0,0242	7,8023	0,8110	0,1104	0,8450	0,0000	0,2000
1202	20,2222	2,2222	0,2263	0,4312	0,0000	0,0256	7,1472	0,7937	0,1246	0,7230	0,0000	0,2493
1092	18,1667	2,2222	0,2271	0,4318	0,0000	0,0294	6,4920	0,7720	0,1260	0,6120	0,0000	0,2203
982	16,3333	2,2222	0,2526	0,4354	0,0000	0,0347	5,8360	0,7474	0,1315	0,5510	0,0000	0,2205
882	14,6667	2,2222	0,2813	0,4371	0,0000	0,0391	5,2413	0,7187	0,1334	0,4660	0,0000	0,2047
762	12,6667	2,2222	0,3257	0,4379	0,0000	0,0432	4,5269	0,6743	0,1434	0,3550	0,0000	0,1000
612	10,1667	2,2222	0,4058	0,4426	0,0000	0,0036	3,6331	0,5942	0,1427	0,2570	0,0000	0,1922
432	7,1667	2,2222	0,5756	0,4492	0,0000	0,0582	2,5611	0,4244	0,1599	0,1470	0,0000	0,1102
512	8,5707	2,2222	0,4853	0,4522	0,0000	0,0717	3,0375	0,5147	0,1765	0,2200	0,0000	0,1200
342	5,6667	2,2222	0,7283	0,4336	0,0000	0,1600	2,0250	0,2720	0,1213	0,0630	0,0000	0,0700
227	3,4523	2,2222	1,1958	-0,1929	0,0000	0,0101	1,2329	-0,1950	-6,3509	-0,1340	0,0000	0,0052

METHOD II(VOLPICH)

RPM	(T*12**3)/(RHO*D**3)	(Q*12**4)/(RHO*D**4)	VA	VA/SQRT(D/12)	SQRT(ND/12)	NSQRT(D/12)	ETA	EFFECTIVE SLIP
1522	6,6444	5,2156	3,1973	4,9533	25,1661	981,1558	0,1037	0,0191
1422	6,4459	5,1257	3,1973	4,9533	24,3242	916,0001	0,1099	0,0063
1312	6,2326	4,8122	3,1973	4,9533	23,3031	845,0014	0,1104	0,7901
1272	5,1599	4,2727	3,1973	4,9533	22,3687	774,5967	0,1246	0,7700
1392	4,3677	3,9110	3,1973	4,9533	21,3112	703,5928	0,1260	0,7477
982	3,9324	3,7760	3,1973	4,9533	20,2273	632,5873	0,1325	0,7194
882	3,3259	3,5277	3,1973	4,9533	19,1485	568,0376	0,1334	0,6079
762	2,5335	2,9776	3,1973	4,9533	17,7951	498,5779	0,1434	0,6301
612	1,8342	2,6278	3,1973	4,9533	15,9426	393,7533	0,1427	0,5491
432	1,2491	1,3894	3,1973	4,9533	13,3853	277,5038	0,1599	0,3604
512	1,5731	2,1592	3,1973	4,9533	14,5774	329,2036	0,1765	0,4007
342	2,4494	1,3439	3,1973	4,9533	11,9024	219,4691	0,1213	0,1911
227	-0,9563	2,2899	3,1973	4,9533	9,2871	133,6179	-6,3502	-0,3206

THEMIS PROJECT NUMBER 1 HIGH SPEED PADDLEWHEEL OCTOBER 1960

NUMBER OF BLADES= 12 D=5,0000 LITTLE D/D=0,1000 LITTLE D= 0,500 V0= 7,730

METHOD I

RPM	LITTLE N	LITTLE H	LAMBDA SUB 1	KT	KL	KQ	FROUDE NO.	SLIP	ETA	T	L	Q
1322	22,2202	2,2002	0,2674	0,0335	0,0000	0,0348	7,8619	0,7320	0.1300	0,9500	0.0000	0,4095
1182	19,6667	2,0222	0,2991	0,2309	0,0000	0,0385	7,0200	0.7009	0.1201	0,6900	0.0000	0,3023
1232	22,5002	2,2402	0,2872	0,2312	0,0000	0,0375	7.3250	0.7130	0.1185	0,7600	0.0000	0,3032
1292	18,1667	2,2702	0,3230	0,2311	0,0000	0,0425	6,4920	0.6762	0.1186	0,6000	0.0000	0,3413
1212	16,8333	2,2202	0,3495	0,2319	0,0000	0,0446	6,0155	0.6085	0.1249	0,5270	0.0000	0,3072
942	15,6667	2,2202	0,3755	0,2316	0,0000	0,0492	5,5906	0.6245	0.1285	0,4530	0.0000	0,2940
862	14,3333	2,0022	0,4174	0,2341	0,0000	0,0557	5,1221	0.5896	0.1257	0,4090	0.0000	0,2702
732	12,1667	2,0202	0,4835	0,2473	0,0000	0,0751	4,3479	0.5165	0.1524	0,4098	0.0000	0,2703
642	10,6667	2,2222	0,5515	0,2580	0,0000	0,0854	3,8118	0,4485	0.1072	0,3050	0.0000	0,2303
522	9,6667	2,2002	0,6788	0,2335	0,0000	0,0833	3,0971	0.3212	0.1365	0,1470	0.0000	0,152
425	7,0833	2,2022	0,8325	-0,0126	0,0000	0,0587	2,5313	0.1695	-0.0984	-0,0370	0.0000	0,0700
342	5,6667	2,2022	1,0381	-0,0325	0,0000	0,0202	2,0250	-0,0381	-0.0376	-0,0610	0.0000	0,0130
322	5,3333	2,2202	1,1697	-0,1426	0,0000	0,0043	1,7987	-0,1087	10.9916	-0,2080	0.0000	0,0027

METHOD II(VOLPIC-)

RPM	(T*12**3)/(RHO*D**3)	(Q*12**4)/(RHO*D**4)	VA	VA/SQRT(D/12)	SQRT(ND/12)	NSQRT(D/12)	ETA	EFFECTIVE SLIP
1322	6,6228	7,0141	4,5592	7,0630	23,4521	852.0563	0,1300	0,7029
1182	4,9015	6,2047	4,5592	7,0630	22,1736	761.6867	0,1201	0,6677
1232	5,4242	6,5644	4,5592	7,0630	22,0305	793.9016	0,1185	0,0012
1292	4,2021	5,8458	4,5592	7,2632	21,3112	783.5920	0,1180	0,6402
1212	3,7611	5,2613	4,5592	7,8638	20,5142	851.9522	0,1249	0,6117
942	3,2337	5,2357	4,5592	7,0630	19,7906	686.7674	0,1205	0,5020
862	2,9197	4,7662	4,5592	7,0630	18,9297	555.1276	0,1257	0,5440
732	2,9197	4,6324	4,5592	7,0630	17,4484	471.2138	0,1524	0,4620
642	2,7477	4,2466	4,5592	7,0632	16,3299	413.1182	0,1072	0,3872
522	1,6491	2,6078	4,5592	7,0638	14,7190	325.6586	0,1365	0,2458
425	-2,2641	1,2133	4,5592	7,0630	13,3073	274.3363	-0,0984	0,0772
342	-2,4353	2,2698	4,5592	7,0638	11,9024	219.4691	-0,0376	-0,1534
322	-1,4845	0,2457	4,5592	7,0630	11,2175	194.9402	-18,9907	-0,2900

THEMIS PROJECT NUMBER 1   HIGH SPEED PADDLEWHEEL   OCTOBER 1960

NUMBER OF BLADES= 12   D=5,0000   LITTLE D/D=0.1600   LITTLE D= 0,000   V0= 3,000

METHOD I

RPM	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KQ	FROUDE NO.	SLIP	ETA	T	L	Q
1650	27,5000	1,7000	0,1000	0,0191	0,0000	0,0119	9,0273	0.9000	0.0084	0,0450	0,0000	0,2109
1500	25,0000	1,7000	0,1100	0,0285	0,0000	0,0135	8,9340	0,8900	0.0836	0,7470	0.0000	0,2047
1230	20,5000	1,7000	0,1342	0,0249	0,0000	0,0162	7,3250	0.8650	0.1035	0,6120	0.0000	0,1653
1020	17,0000	1,7000	0,1618	0,0298	0,0000	0,0233	6,0751	0,8382	0.1105	0,5020	0.0000	0,1420
790	13,1667	1,7000	0,2299	0,2307	0,0000	0,0200	4,7052	0,7911	0.1443	0,3920	0,0000	0,1103
530	8,8333	1,7000	0,3114	0,0511	0,0000	0,0490	3,1567	0.6686	0.1599	0,2330	0.0000	0,0949
390	6,5000	1,7000	0,4231	0,2397	0,0000	0,0760	2,3220	0.5769	0.1097	0,0980	0,0000	0,0700
260	4,3333	1,7000	0,6347	0,0219	0,0000	0,1034	1,5486	0.3653	0,0672	0,0240	0,0000	0,0473
100	1,6667	1,7000	1,6522	-1,0129	0.0000	-0,2331	0,5956	-0,6582	0.4173	-0,2940	0,0000	-0,0190

METHOD II(VOLPICH)

RPM	(T*12**3)/(RHO*D**3)	(Q*12**4)/(RHO*D**4)	VA	VA/SQRT(D/12)	SQRT(ND/12)	NSQRT(D/12)	ETA	EFFECTIVE SLIP
1650	6,8325	3,7497	2,1316	3,3022	26,2202	1065,0704	0,0884	0,0009
1500	5,3312	3,5278	2,1316	3,3022	25,0000	968,2458	0,0836	0,0690
1230	4,3677	2,8319	2,1316	3,3022	22,0385	793,9616	0,1035	0,0403
1020	3,5827	2,4465	2,1316	3,3022	20,6155	658,4072	0,1135	0,0074
790	2,7976	2,0254	2,1316	3,3022	18,1430	509,9420	0,1443	0,7513
530	1,6629	1,6186	2,1316	3,3022	14,8605	342,1135	0,1599	0,6293
390	2,6794	1,3459	2,1316	3,3022	12,7475	251,7439	0,1097	0,4963
260	2,1713	0,8293	2,1316	3,3022	10,4083	167,8293	0,0672	0,2444
100	-2,0987	-2,2690	2,1316	3,3022	6,4550	64,5[illegible]7	0,4170	-9,9645

THEMIS PROJECT NUMBER 1   HIGH SPEED PADDLEWHEEL   OCTOBER 1968

NUMBER OF BLADES= 12   D=5,0000   LITTLE D/D=0,1600   LITTLE D= 0,800   VB= 4,000

METHOD I

RPM	LITTLE N	LITTLE H	LAMBDA SUB 1	KT	KL	KQ	FROUDE NO,	SLIP	ETA	T	L	Q
1472	24,5222	1,7222	2,1434	0,0301	0,0000	0,0192	0,7593	0,8506	0,1122	1,0940	0,0000	0,2000
1362	22,6667	1,7222	2,1552	0,0319	0,0000	0,0189	8,1081	0,8458	0,1307	0,9560	0,0000	0,2303
1262	21,2222	1,7222	2,1673	0,0333	0,0000	0,0228	7,5845	0,8327	0,1225	0,8500	0,0000	0,2442
1122	18,3333	1,7222	2,1917	0,0362	0,0000	0,0266	6,5916	0,8083	0,1302	0,7100	0,0000	0,2170
982	16,3333	1,7222	2,2122	0,0393	0,0000	0,0303	5,8360	0,7848	0,1394	0,6120	0,0000	0,1900
885	14,7500	1,7222	2,2383	0,0444	0,0000	0,0342	5,2710	0,7617	0,1545	0,5640	0,0000	0,1012
722	12,0222	1,7222	2,2929	0,0554	0,0000	0,0427	4,2083	0,7071	0,1934	0,4600	0,0000	0,1470
615	10,2500	1,7222	2,3429	0,0559	0,0000	0,0555	3,6629	0,6571	0,1720	0,3430	0,0000	0,1417
482	8,2222	1,7222	2,4393	0,0557	0,0000	0,0826	2,8509	0,5607	0,1479	0,2000	0,0000	0,1207
395	6,5833	1,7222	2,5330	0,0435	0,0000	0,0946	2,3526	0,4662	0,1226	0,1100	0,0000	0,0090
282	4,6667	1,7222	2,7531	0,0094	0,0000	0,1139	1,6077	0,2469	0,0312	0,0120	0,0000	0,0003
175	2,9167	1,7222	1,2249	-0,2215	0,0000	0,2537	1,0423	-0,2049	-2,6297	-0,1100	0,0000	0,0109
145	2,4167	1,7222	1,4542	-0,9700	0,0000	-0,0551	0,8036	-0,4942	12,0013	-0,3310	0,0000	-0,0070

METHOD II(VOLPICH)

RPM	(T*12**3)/(RHO*D**3)	(Q*12**4)/(RHO*D**4)	VA	VA/SQRT(D/12)	SQRT(ND/12)	NSQRT(D/12)	ETA	EFFECTIVE SLIP
1472	7,5222	4,8182	2,7237	4,2195	24,7487	948.8809	0,1121	0,0292
1362	6,8225	4,0466	2,7237	4,2195	23,8048	877.0762	0,1307	0,0154
1262	6,1234	4,1822	2,7237	4,2195	22,9129	813.3265	0,1225	0,0000
1122	5,2571	3,7311	2,7237	4,2195	21,4087	718.0469	0,1302	0,7718
982	4,3677	3,3714	2,7237	4,2195	20,2073	632.5073	0,1394	0,7439
885	4,2252	3,1231	2,7237	4,2195	19,2229	571.2650	0,1545	0,7164
722	3,3258	2,5179	2,7237	4,2195	17,3205	464.7580	0,1934	0,6514
615	2,4479	2,4279	2,7237	4,2195	16,0078	396.9808	0,1720	0,5910
482	1,4845	2,2238	2,7237	4,2195	14,1421	309.0387	0,1479	0,4770
395	0,735[illegible]	1,7086	2,7237	4,2195	12,0290	254.9714	0,1226	0,3649
282	0,[illegible]56	1,2334	2,7237	4,2195	10,0012	180.7392	0,0312	0,1839
175	-0,7[illegible]5[illegible]	0,1798	2,7237	4,2195	8,5391	112.9628	-2,6295	-0,4344
145	-0,3423	-0,1342	2,7237	4,2195	7,7720	93.5971	12,0007	-0,7312

THEMIS PROJECT NUMBER 1 HIGH SPEED PADDLEWHEEL OCTOBER 1968

NUMBER OF BLADES= 12 D=5,0000 LITTLE D/D=0,1600 LITTLE D= 0,000 V0= 9,400

METHOD I

RPM	LITTLE N	LITTLE H	LAMBDA SUB 1	KT	KL	KQ	FROUDE NO,	SLIP	ETA	T	L	Q
1600	26,6667	1,7222	0,1547	0,0313	0,0000	0,0252	9,5295	0.8453	0.0960	1,2000	0.0000	0,4350
1400	23,3333	1,7222	0,1760	0,0366	0,0000	0,0325	8,3384	0.8232	0.0996	1,1640	0.0000	0,4305
1350	22,5000	1,7222	0,1834	0,0361	0,0000	0,0315	8,0486	0.8166	0.1046	1,0660	0.0000	0,3005
1240	20,6667	1,7222	0,1996	0,0373	0,0000	0,0364	7,3854	0.8034	0.1024	0,9310	0.0000	0,3700
1260	18,3333	1,7222	0,2292	0,0363	0,0000	0,0413	6,4324	0.7720	0.1086	0,6060	0.0000	0,3255
870	14,5000	1,7222	0,2845	0,0459	0,0000	0,0493	5,1817	0.7155	0.1327	0,5640	0.0000	0,2520
720	12,0000	1,7222	0,3438	0,0481	0,0000	0,0614	4,2083	0.6562	0.1344	0,4840	0.0000	0,2153
555	9,2500	1,7222	0,4450	0,0416	0,0000	0,0782	3,3056	0.5540	0.1187	0,3060	0.0000	0,1620
380	6,3333	1,7222	0,6514	0,0158	0,0000	0,1184	2,2633	0.3406	0.0435	0,0370	0.0000	0,1155
320	5,3333	1,7222	0,8251	-0,0336	0,0000	0,1165	1,7060	0.1749	-0.1109	-0,0490	0.0000	0,0700
275	3,4167	1,7222	1,2274	-0,2076	0,0000	0,2276	1,2210	-0,2674	-6.2941	-0,1940	0.0000	0,0070

METHOD II(VOLPICH)

RPM	(T*12**3)/(R*C*D**3)	(Q*12**4)/(RHO*D**4)	VA	VA/SQRT(D/12)	SQRT(ND/12)	NSQRT(D/12)	ETA	EFFECTIVE SLIP
1600	9,2636	7,4637	3,1973	4,9533	25,8199	1032.7956	0,0960	0,0150
1400	8,3772	7,3736	3,1973	4,9533	24,1523	903.6961	0,0996	0,7095
1350	7,6073	6,6544	3,1973	4,9533	23,7171	871.4212	0,1040	0,70x7
1240	6,6444	6,4745	3,1973	4,9533	22,7303	800.4166	0,1024	0,7624
1260	4,5559	5,5753	3,1973	4,9533	21,2132	697.1370	0,1006	0,7272
870	4,2257	4,3163	3,1973	4,9533	19,0394	561.5026	0,1327	0,6613
720	2,8833	3,6259	3,1973	4,9533	17,3205	464.7582	0,1344	0,5987
555	1,4545	2,7876	3,1973	4,9533	15,2069	358.2510	0,1107	0,4691
380	0,2541	1,9763	3,1973	4,9533	12,5831	245.2009	0,0435	0,2245
320	-0,3497	1,2133	3,1973	4,9533	11,1803	193.6492	-0,1109	0,0170
275	-1,3980	0,1342	3,1973	4,9533	9,2421	132.3269	-6,2930	-0,4374

THEMIS PROJECT NUMBER 1 HIGH SPEED PADDLEWHEEL OCTOBER 1966

NUMBER OF BLADES= 12 D=5.0000 LITTLE D/D=0.1600 LITTLE D= 0.800 VS= 7.700

METHOD I

RPM	LITTLE N	LITTLE H	LAMBDA SUB 1	KT	KL	KQ	FROUDE NO.	SLIP	ETA	T	L	Q
1350	22.5000	1.7000	2.2614	0.0365	0.0000	0.0495	8.0436	0.7386	0.0964	1.0700	0.0000	0.0095
1300	21.6667	1.7000	2.2715	0.0371	0.0000	0.0497	7.7428	0.7285	0.1015	1.0170	0.0000	0.5870
1190	19.8333	1.7000	2.2966	0.0352	0.0000	0.0554	7.0876	0.7034	0.0942	0.9000	0.0000	0.5302
1090	18.1667	1.7000	2.3238	0.0331	0.0000	0.0602	6.4920	0.6762	0.0890	0.6370	0.0000	0.4830
1000	16.6667	1.7000	2.3532	0.0317	0.0000	0.0653	5.9560	0.6479	0.0857	0.5140	0.0000	0.4410
630	14.5000	1.7000	2.5672	0.0494	0.0000	0.1135	3.7523	0.4390	0.1219	0.3100	0.0000	0.3845
510	8.5000	1.7000	2.6921	0.0348	0.0000	0.1272	3.0375	0.3079	0.0950	0.1473	0.0000	0.2232
420	7.0000	1.7000	2.8434	-0.0425	0.0000	0.1211	2.5015	0.1596	-0.1400	-0.1220	0.0000	0.1443
METHOD II(VSSBBC-)		1.7000	1.1232	-0.1997	0.0000	0.0835	1.9059	-0.1030	-1.3170	-0.3310	0.0000	0.0970

RPM	(T*12**3)/(R*D*D**3)	(Q*12**4)/(RHO*D**4)	VA	VA/SQRT(D/12)	SQRT(ND/12)	NSQRT(D/12)	ETA	EFFECTIVE SLIP
1350	7.6935	17.4312	4.5592	7.2630	23.7171	871.4212	0.0964	0.6082
1300	7.2561	7.7118	4.5592	7.2632	23.2737	839.1464	0.1014	0.0720
1190	5.7445	9.0523	4.5592	7.2632	22.2673	760.1417	0.0942	0.6429
1090	4.5461	8.2732	4.5592	7.2630	21.3112	703.5929	0.0890	0.6149
1000	3.6553	7.5536	4.5592	7.2630	20.4124	645.4972	0.0857	0.5792
630	2.2495	5.2156	4.5592	7.2630	16.2019	486.0633	0.1219	0.3330
510	1.0491	3.9225	4.5592	7.2630	14.9774	329.2036	0.0950	0.1721
420	-2.0727	2.4722	4.5592	7.2630	13.2288	271.1689	-0.1400	-0.0004
320	-2.3423	2.9892	4.5592	7.2630	11.5470	206.5591	-1.3170	-0.3131

THEMIS PROJECT NUMBER 1 HIGH SPEED PADDLEWHEEL OCTOBER 1968

NUMBER OF BLADES= 6 D=5,0000 LITTLE D/D=0,0000 LITTLE D= 0,300 VB= 4,600

METHOD I

RPM	LITTLE N	LITTLE H	LAMBDA SUB 1	KT	KL	KQ	FROUDE NO,	SLIP	ETA	T	L	S
1480	24,6667	2,2000	0,1425	0,0228	0,0000	0,0147	8,0140	0,8575	0.1011	0,7390	0.0000	0,2170
1420	23,3333	2,2000	0,1536	0,0225	0,0000	0,0153	8,3304	0,8494	0.1100	0,7150	0.0000	0,2025
1335	22,2500	2,2000	0,1579	0,0228	0,0000	0,0157	7,9512	0,8421	0.1140	0,6900	0.0000	0,1806
1240	20,6667	2,2000	0,1720	0,0259	0,0000	0,0169	7,3094	0,8300	0.1250	0,6240	0.0000	0,1757
1170	19,5000	2,2000	0,1832	0,0265	0,0000	0,0184	6,9695	0,8190	0.1297	0,5890	0.0000	0,1709
1040	17,3333	2,2000	0,2027	0,0312	0,0000	0,0212	6,1942	0,7973	0.1400	0,5430	0.0000	0,1550
920	15,3333	2,2000	0,2292	0,0353	0,0000	0,0253	5,4795	0,7700	0.1601	0,4050	0.0000	0,1447
782	13,0333	2,2000	0,2703	0,0422	0,0000	0,0328	4,6457	0,7297	0.1778	0,4160	0.0000	0,1317
630	10,5000	2,2000	0,3347	0,0485	0,0000	0,0395	3,7523	0,6693	0.2054	0,3120	0.0000	0,1059
510	8,5000	2,2000	0,4134	0,0548	0,0000	0,0514	3,2379	0,5066	0.2201	0,2310	0.0000	0,0804
420	6,6667	2,2000	0,5271	0,0462	0,0000	0,0526	2,3024	0,4729	0.2319	0,1200	0.0000	0,0560
322	5,3333	2,2000	0,6959	0,0277	0,0000	0,0411	1,9059	0,3411	0.2222	0,0460	0.0000	0,0204
212	3,5000	2,2000	1,0041	0,0300	0,0000	0,0173	1,2980	-0,0041	0.0000	0,0000	0.0000	0,0052
125	2,0833	2,2000	1,6868	-0,2723	0,0000	-0,0409	0,7449	-0,6660	4.6932	-0,0690	0.0000	-0,0052

METHOD II(VOLPICH)

RPM	(T*12**3)/(RHO*D**3)	(Q*12**4)/(RHO*D**4)	VA	VA/SQRT(D/12)	SQRT(ND/12)	NSQRT(D/12)	ETA	EFFECTIVE SLIP
1480	5,2741	3,7169	2,7237	4,2195	24,8320	955.3359	0,1011	0,8484
1420	5,1728	3,4685	2,7237	4,2195	24,1923	903.6961	0,1100	0,8390
1335	4,6960	3,2321	2,7237	4,2195	23,5058	861.7300	0,1140	0,8320
1240	4,4534	3,0089	2,7237	4,2195	22,7303	800.4166	0,1250	0,8191
1170	4,2736	2,9204	2,7237	4,2195	22,0794	755.2317	0,1297	0,8003
1040	3,8753	2,6549	2,7237	4,2195	20,8167	671.3171	0,1400	0,7843
920	3,4614	2,4779	2,7237	4,2195	19,5789	593.8574	0,1601	0,7562
782	2,9689	2,2567	2,7237	4,2195	18,0278	503.4070	0,1770	0,7124
630	2,2267	1,8142	2,7237	4,2195	16,2019	406.6633	0,2054	0,6439
510	1,6486	1,5487	2,7237	4,2195	14,5774	329.2036	0,2260	0,5602
400	0,8564	0,9735	2,7237	4,2195	12,9099	258.1989	0,2319	0,4392
322	0,3283	0,4867	2,7237	4,2195	11,5470	206.5591	0,2722	0,2992
210	0,0700	0,2885	2,7237	4,2195	9,3541	135.5944	0,0660	-0,0602
125	-0,4924	-0,0885	2,7237	4,2195	7,2169	80.6872	4,6938	-0,7945

THEMIS PROJECT NUMBER 1 HIGH SPEED PADDLEWHEEL OCTOBER 1968

NUMBER OF BLADES= 6 D=5.0000 LITTLE O/D=0.0600 LITTLE D= 0.300 VO= 9.400

METHOD I

RPM	LITTLE N	LITTLE H	LAMBDA SUB 1	KT	KL	KQ	FROUDE NO.	SLIP	ETA	T	L	Q
1550	25.8333	2.2000	0.1597	0.0282	0.0000	0.0210	9.2317	0.8403	0.1070	1.0970	0.0000	0.3419
1440	24.0000	2.2000	0.1719	0.0302	0.0000	0.0226	8.5766	0.8281	0.1151	1.0160	0.0000	0.3162
1340	22.3333	2.2000	0.1847	0.0321	0.0000	0.0243	7.9810	0.8153	0.1223	0.9360	0.0000	0.2945
1220	20.3333	2.2000	0.2029	0.0371	0.0000	0.0277	7.2663	0.7971	0.1357	0.8960	0.0000	0.2790
1160	19.3333	2.2000	0.2134	0.0376	0.0000	0.0290	6.9089	0.7866	0.1383	0.8200	0.0000	0.2639
1060	17.6667	2.2000	0.2335	0.0418	0.0000	0.0322	6.3133	0.7665	0.1517	0.7620	0.0000	0.2443
990	16.5000	2.2000	0.2520	0.0414	0.0000	0.0335	5.8964	0.7580	0.1543	0.6580	0.0000	0.2222
880	14.6667	2.2000	0.2813	0.0451	0.0000	0.0375	5.2413	0.7187	0.1689	0.5660	0.0000	0.1963
730	12.1667	2.2000	0.3391	0.0486	0.0000	0.0445	4.3479	0.6609	0.1852	0.4280	0.0000	0.1602
620	10.3333	2.2000	0.4125	0.0522	0.0000	0.0573	3.5736	0.5875	0.1879	0.3050	0.0000	0.1395
495	8.2500	2.2000	0.5001	0.0551	0.0000	0.0693	2.9482	0.4999	0.1990	0.2190	0.0000	0.1147
425	7.0833	2.2000	0.5824	0.0434	0.0000	0.0656	2.5313	0.4176	0.1924	0.1270	0.0000	0.0801
325	5.4167	2.2000	0.7616	0.0070	0.0000	0.0324	1.9357	0.2384	0.0879	0.0120	0.0000	0.0217
190	3.1667	2.2000	1.3028	-0.0786	0.0000	0.0307	1.1316	-0.3028	0.0000	-0.0460	0.0000	0.0900

METHOD II(VOLPICH)

RPM	(T*12**3)/(RHO*D**3)	(Q*12**4)/(RHO*D**4)	VA	VA/SQRT(D/12)	SQRT(ND/12)	NSQRT(D/12)	ETA	EFFECTIVE SLIP
1550	7.8291	5.8400	3.1973	4.9533	25.4133	1000.3207	0.1070	0.8381
1440	7.2512	5.4154	3.1973	4.9533	24.4949	929.5160	0.1151	0.8171
1340	6.6901	5.2443	3.1973	4.9533	23.6291	864.9663	0.1223	0.8035
1220	6.3946	4.7788	3.1973	4.9533	22.5462	787.5066	0.1397	0.7842
1160	5.8522	4.5133	3.1973	4.9533	21.9848	748.7760	0.1383	0.7730
1060	5.4382	4.1850	3.1973	4.9533	21.0159	684.2271	0.1517	0.7516
990	4.6960	3.8253	3.1973	4.9533	20.3101	639.0423	0.1543	0.7340
880	4.0394	3.3629	3.1973	4.9533	19.1485	568.0376	0.1689	0.7000
730	2.9975	2.7434	3.1973	4.9533	17.4404	471.2130	0.1852	0.6393
620	2.1767	2.3894	3.1973	4.9533	15.8114	307.2983	0.1879	0.5611
495	1.5637	1.9640	3.1973	4.9533	14.3614	319.5211	0.1990	0.4600
425	0.9064	1.3717	3.1973	4.9533	13.3073	274.3363	0.1924	0.3804
325	0.0856	0.3711	3.1973	4.9533	11.6339	209.7866	0.0879	0.1098
190	-0.3283	0.0030	3.1973	4.9533	8.8976	122.6445	0.0000	-0.3059

THEMIS PROJECT NUMBER 1 HIGH SPEED PADDLEWHEEL OCTOBER 1968

NUMBER OF BLADES= 6 D=5,0000 LITTLE D/D=0,0600 LITTLE D= 0,300 VB= 7,700

METHOD I

RPM	LITTLE N	LITTLE H	LAMBDA SUB 1	KT	KL	KQ	FROUDE NO,	SLIP	ETA	T	L	Q
1530	25,5000	2,2000	0,2307	0,0335	0,0000	0,0287	9,1126	0,7693	0.1343	1,2710	0,0000	0,4547
1430	23,8333	2,2000	0,2468	0,0388	0,0000	0,0329	8,5170	0,7537	0.1424	1,2590	0,0000	0,4947
1340	22,3333	2,2000	0,2634	0,0401	0,0000	0,0345	7,9010	0,7366	0,1530	1,1670	0,0000	0,4105
1240	20,6667	2,2000	0,2846	0,0417	0,0000	0,0378	7,3054	0,7154	0.1571	1,0400	0,0000	0,3927
1140	19,0000	2,2000	0,3096	0,0449	0,0000	0,0382	6,7098	0,6984	0.1819	0,9472	0,0000	0,3350
1040	17,3333	2,2000	0,3394	0,0510	0,0000	0,0447	6,1942	0,6606	0.1936	0,8942	0,0000	0,3265
930	15,5000	2,2000	0,3795	0,0580	0,0000	0,0523	5,5390	0,6205	0.2102	0,8132	0,0000	0,3050
790	13,1667	2,2000	0,4468	0,0833	0,0000	0,0662	4,7052	0,5532	0.2012	0,6430	0,0000	0,2770
730	12,1667	2,2000	0,4835	0,0673	0,0000	0,0631	4,3479	0,5169	0.2579	0,5820	0,0000	0,2273
660	11,0000	2,2000	0,5348	0,0556	0,0000	0,0579	3,9309	0,4652	0.2560	0,3932	0,0000	0,1785
610	10,1667	2,2000	0,5786	0,0441	0,0000	0,0514	3,6331	0,4214	0.2482	0,2660	0,0000	0,1292
530	8,8333	2,2000	0,6659	0,0279	0,0000	0,0449	3,1567	0,3341	0.2067	0,1270	0,0000	0,0852
425	7,0833	2,2000	0,8325	0,0000	0,0000	0,0212	2,5313	0,1695	0.0000	0,0000	0,0000	0,0290
255	4,2500	2,2000	1,3841	-0,0654	0,0000	0,0000	1,5108	-0,3841	0.0000	-0,0690	0,0000	0,0000

METHOD II(VOLPICH)

RPM	(T*12**3)/(RHO*D**3)	(Q*12**4)/(RHO*D**4)	VA	VA/SQRT(D/12)	SQRT(ND/12)	NSQRT(D/12)	ETA	EFFECTIVE SLIP
1530	9,0709	7,7877	4,5592	7,0630	25,2400	987,6100	0,1343	0,7546
1430	8,9852	7,7877	4,5592	7,0630	24,4897	923,0018	0,1424	0,7374
1340	8,3287	7,1682	4,5592	7,0630	23,0291	864,9663	0,1530	0,7198
1240	7,4223	6,7257	4,5592	7,0630	22,7303	808,4166	0,1571	0,6972
1140	6,7586	5,7523	4,5592	7,0630	21,7945	735,8660	0,1819	0,6706
1040	6,3803	5,5924	4,5592	7,0630	20,8167	671,3171	0,1936	0,6390
930	5,8222	5,2384	4,5592	7,0630	19,6850	600,3124	0,2102	0,5963
790	6,0163	4,7708	4,5592	7,0630	18,1438	509,9420	0,2012	0,5247
730	4,1536	3,8938	4,5592	7,0630	17,4484	471,2130	0,2579	0,4856
660	2,8740	2,9224	4,5592	7,0630	15,5831	426,0282	0,2560	0,4311
610	1,8984	2,2124	4,5592	7,0630	15,9426	393,7533	0,2402	0,3845
530	0,9264	1,4622	4,5592	7,0630	14,8085	342,1135	0,2067	0,2915
425	0,0700	0,4425	4,5592	7,0630	13,3073	274,3363	0,0000	0,1165
255	-0,4924	0,0000	4,5592	7,0630	10,3078	164,0818	0,0000	-0,4725

EXIT
*C

.SEC
CONFIRM: JOB 6, USER [500,65] LOGGED OFF TTY41 1855 2-JUN-70
DELETED ALL 2 FILES (INCLUDING UFD, 11, DISK BLOCKS)
RUNTIME 2 MIN, 35,29 SEC

THEMIS PROJECT NUMBER 1 HIGH SPEED PADDLEWHEEL OCTOBER 1969

NUMBER OF BLADES= 6 D=5.0000 LITTLE D/D=0.1000 LITTLE D= 0.500 VB= 4.000

METHOD I

RPM	LITTLE N	LITTLE H	LAMBDA SUB 1	KT	KL	KQ	FROUDE NO.	SLIP	ETA	T	L	Q
1500	25.0000	2.0000	0.1426	0.0257	0.0000	0.0182	8.9348	0.8594	0.0992	0.9360	0.0000	0.2764
1400	23.3333	2.0000	0.1576	0.0287	0.0000	0.0287	8.3384	0.8494	0.1045	0.9120	0.0000	0.2730
1260	21.0000	2.0000	0.1673	0.0318	0.0000	0.0224	7.5845	0.8327	0.1190	0.8200	0.0000	0.2402
1160	19.3333	2.0000	0.1810	0.0355	0.0000	0.0241	6.9889	0.8182	0.1335	0.7740	0.0000	0.2190
1045	17.4167	2.0000	0.2018	0.0424	0.0000	0.0291	6.2240	0.7982	0.1404	0.7160	0.0000	0.2144
970	16.1667	2.0000	0.2174	0.0454	0.0000	0.0341	5.7773	0.7826	0.1446	0.6930	0.0000	0.2170
890	14.8333	2.0000	0.2369	0.0486	0.0000	0.0367	5.3088	0.7651	0.1569	0.6240	0.0000	0.1963
810	13.5000	2.0000	0.2673	0.0512	0.0000	0.0402	4.8243	0.7397	0.1692	0.5430	0.0000	0.1702
740	12.3333	2.0000	0.2849	0.0522	0.0000	0.0454	4.4074	0.7151	0.1633	0.4620	0.0000	0.1079
580	9.6667	2.0000	0.3635	0.0552	0.0000	0.0489	3.4545	0.6355	0.2045	0.3000	0.0000	0.1111
650	10.8333	2.0000	0.3244	0.0522	0.0000	0.0489	3.8714	0.6755	0.1734	0.3580	0.0000	0.1395
390	6.5000	2.0000	0.5417	0.0543	0.0000	0.0935	2.3228	0.4593	0.2451	0.2200	0.0000	0.0956
325	5.4167	2.0000	0.6406	0.0946	0.0000	0.0032	1.9357	0.3512	0.3685	0.1620	0.0000	0.0594
225	3.7500	2.0000	0.9371	0.2146	0.0000	0.0332	1.3481	0.0629	0.2267	0.0120	0.0000	0.0183
165	2.7500	2.0000	1.2779	-0.1042	0.0000	-0.0281	0.9827	-0.2779	2.3783	-0.0460	0.0000	-0.0052

METHOD II(VOLPICH)

RPM	(T*12**3)/(RHO*D**3)	(Q*12**4)/(RHO*D**4)	VA	VA/SQRT(D/12)	SQRT(ND/12)	NSQRT(D/12)	ETA	EFFECTIVE SLIP
1500	6.6021	4.7346	2.7237	4.2195	25.0000	968.2458	0.0992	0.8430
1400	6.5788	4.6923	2.7237	4.2195	24.1523	903.4961	0.1049	0.8327
1260	5.8522	4.1151	2.7237	4.2195	22.9120	813.3255	0.1198	0.8141
1160	5.5239	3.7611	2.7237	4.2195	21.9048	748.7768	0.1335	0.7900
1045	5.1122	3.6726	2.7237	4.2195	20.8666	674.5446	0.1404	0.7750
970	4.9458	3.7169	2.7237	4.2195	20.1039	626.1323	0.1446	0.7585
890	4.4534	3.3629	2.7237	4.2195	19.2578	574.4929	0.1569	0.7360
810	3.8753	3.2531	2.7237	4.2195	18.3712	522.0528	0.1652	0.7100
740	3.2972	2.8761	2.7237	4.2195	17.5594	477.6679	0.1633	0.6834
580	2.1417	1.9727	2.7237	4.2195	15.5456	374.3804	0.2045	0.5961
650	2.5557	2.3894	2.7237	4.2195	16.4578	419.5732	0.1734	0.6396
390	1.4845	1.6372	2.7237	4.2195	12.7475	251.7439	0.2451	0.3993
325	1.1562	1.2177	2.7237	4.2195	11.6369	209.7866	0.3685	0.2791
225	0.2856	0.1772	2.7237	4.2195	9.6825	149.2369	0.2267	-0.0413
165	-2.3253	-2.2835	2.7237	4.2195	8.2916	136.5870	2.3782	-0.4199

EXIT

THEMIS PROJECT NUMBER 1 HIGH SPEED PADDLEWHEEL OCTOBER 1968

NUMBER OF BLADES= 6 D=5.0000 LITTLE D/D=0.1000 LITTLE D= 0.500 Y0= 5.400

METHOD I

RPM	LITTLE N	LITTLE H	LAMBDA SUB 1	KT	KL	KQ	FROUDE NO.	SLIP	ETA	T	L	Q
1500	25.0000	2.0000	0.1650	0.0361	0.0000	0.0279	8.9340	0.8358	0.1069	1.3170	0.0000	0.4237
1360	22.6667	2.0000	0.1820	0.0468	0.0000	0.0318	8.1001	0.8180	0.1167	1.2240	0.0000	0.3970
1290	21.5000	2.0000	0.1919	0.0398	0.0000	0.0317	7.6032	0.8001	0.1204	1.0740	0.0000	0.3565
1220	20.3333	2.0000	0.2063	0.0472	0.0000	0.0366	7.1472	0.7937	0.1322	1.0970	0.0000	0.3565
1100	18.3333	2.0000	0.2252	0.0453	0.0000	0.0379	6.5516	0.7750	0.1344	0.8090	0.0000	0.3100
1050	17.5000	2.0000	0.2357	0.0466	0.0000	0.0402	6.2538	0.7643	0.1367	0.8340	0.0000	0.2997
963	16.0500	2.0000	0.2570	0.0522	0.0000	0.0466	5.7356	0.7430	0.1440	0.7850	0.0000	0.2919
880	14.6667	2.0000	0.2813	0.0515	0.0000	0.0494	5.2413	0.7187	0.1460	0.6470	0.0000	0.2523
800	13.3333	2.0000	0.3094	0.0479	0.0000	0.0514	4.7648	0.6906	0.1442	0.4070	0.0000	0.2222
700	11.6667	2.0000	0.3536	0.0466	0.0000	0.0577	4.1692	0.6464	0.1426	0.3700	0.0000	0.1912
600	10.0000	2.0000	0.4125	0.0574	0.0000	0.0765	3.5736	0.5879	0.1548	0.3350	0.0000	0.1060
520	8.6667	2.0000	0.4762	0.0554	0.0000	0.0905	3.0971	0.52[illegible]	0.1458	0.2430	0.0000	0.1453
435	7.2500	2.0000	0.5602	0.0523	0.0000	0.1091	2.5900	0.4[illegible]	0.1572	0.1050	0.0000	0.1393
350	5.8333	2.0000	0.7072	0.0292	0.0000	0.0874	2.0846	0.2928	0.1181	0.0500	0.0000	0.0723
325	5.4167	2.0000	0.7616	0.0204	0.0000	0.0724	1.9357	0.2384	0.1075	0.0350	0.0000	0.0517
215	3.5833	2.0000	1.1513	-0.1547	0.0000	0.0000	1.2005	-0.1513	0.0094	-0.1160	0.0000	0.0000

METHOD II(VOLPICH)

RPM	(T*12**3)/(RHO*D**3)	(Q*12**4)/(RHO*D**4)	VA	VA/SQRT(D/12)	SQRT(ND/12)	NSQRT(D/12)	ETA	EFFECTIVE SLIP
1500	9.3992	7.2567	3.1973	4.9533	25.0000	968.2458	0.1069	0.8166
1360	8.7355	6.0142	3.1973	4.9533	23.8040	877.0762	0.1167	0.7970
1290	7.6649	6.1063	3.1973	4.9533	23.1040	832.6914	0.1204	0.7868
1220	7.0291	6.1263	3.1973	4.9533	22.3607	774.5967	0.1322	0.7700
1100	6.3446	5.3298	3.1973	4.9533	21.4007	710.8469	0.1344	0.7500
1050	5.9521	5.1328	3.1973	4.9533	20.9165	677.7721	0.1367	0.7301
963	5.6724	5.7220	3.1973	4.9533	20.0312	621.6130	0.1440	0.7144
880	4.6175	4.4246	3.1973	4.9533	19.1485	568.9376	0.1460	0.6875
800	3.5477	3.8253	3.1973	4.9533	18.2574	516.3975	0.1442	0.6562
700	2.6426	3.2744	3.1973	4.9533	17.0783	451.8401	0.1426	0.6071
600	2.3926	3.1659	3.1973	4.9533	15.0114	387.2983	0.1548	0.5416
520	1.7342	2.8319	3.1973	4.9533	14.7196	335.6586	0.1457	0.4711
435	1.3233	2.3894	3.1973	4.9533	13.4629	280.7913	0.1572	0.3670
350	0.4139	1.2390	3.1973	4.9533	12.0761	225.9240	0.1181	0.2142
325	0.2498	0.8852	3.1973	4.9533	11.6369	209.7866	0.1075	0.1536
215	-0.6279	0.2020	3.1973	4.9533	9.4640	138.7019	0.0000	-0.2792

THEMIS PROJECT NUMBER 1 HIGH SPEED PADDLEWHEEL OCTOBER 1960

NUMBER OF BLADES= 6 D=5.0000 LITTLE D/D=0.1000 LITTLE D= 0.500 VB= 7.700

METHOD I

RPM	LITTLE N	LITTLE H	LAMBDA SUB 1	KT	KL	KQ	FROUDE NO.	SLIP	ETA	T	L	Q
1340	22.3333	2.0000	0.2634	0.0472	0.0000	0.0426	7.8010	0.7366	0.1450	1.3740	0.0000	0.5167
1320	22.0000	2.0000	0.2674	0.0486	0.0000	0.0439	7.8619	0.7326	0.1481	1.3740	0.0000	0.5167
1270	21.1667	2.0000	0.2779	0.0486	0.0000	0.0441	7.5641	0.7221	0.1530	1.2786	0.0000	0.4805
1200	20.0000	2.0000	0.2941	0.0475	0.0000	0.0457	7.1472	0.7059	0.1529	1.1090	0.0000	0.4443
1130	18.8333	2.0000	0.3123	0.0463	0.0000	0.0467	6.7302	0.6877	0.1548	0.9590	0.0000	0.4030
1050	17.5000	2.0000	0.3361	0.0497	0.0000	0.0520	6.2538	0.6639	0.1607	0.8890	0.0000	0.3875
940	15.6667	2.0000	0.3755	0.0565	0.0000	0.0606	5.5986	0.6245	0.1750	0.8090	0.0000	0.3617
840	14.0000	2.0000	0.4202	0.0596	0.0000	0.0748	5.0030	0.5798	0.1957	0.7070	0.0000	0.3565
740	12.3333	2.0000	0.4770	0.0512	0.0000	0.0866	4.4074	0.5230	0.2237	0.7210	0.0000	0.3205
650	10.8333	2.0000	0.5430	0.1079	0.0000	0.1022	3.8714	0.4570	0.2064	0.7390	0.0000	0.2919
575	9.5833	2.0000	0.6138	0.0562	0.0000	0.0883	3.4247	0.3862	0.2994	0.4620	0.0000	0.1973
520	8.6667	2.0000	0.6788	0.0659	0.0000	0.0811	3.0971	0.3212	0.2757	0.2690	0.0000	0.1403
445	7.4167	2.0000	0.7932	0.0252	0.0000	0.0579	2.6504	0.2068	0.1727	0.0012	0.0000	0.0775
380	6.3333	2.0000	0.9285	-0.0149	0.0000	0.0212	2.2633	0.0712	-0.3277	-0.0350	0.0000	0.0207
275	4.5833	2.0000	1.2835	-0.1500	0.0000	0.0000	1.6379	-0.2835	0.0000	-0.1050	0.0000	0.0000

METHOD II(VOLPICH)

RPM	(T*12**3)/(RHO*D**3)	(Q*12**4)/(RHO*D**4)	VA	VA/SQRT(D/12)	SQRT(ND/12)	NSQRT(D/12)	ETA	EFFECTIVE SLIP
1340	9.8760	8.8496	4.5592	7.0630	23.6291	864.9663	0.1450	0.7073
1320	9.8767	8.8496	4.5592	7.0630	23.4521	852.0563	0.1401	0.7029
1270	9.0537	8.2322	4.5592	7.0630	23.0036	819.7815	0.1530	0.6982
1200	7.9147	7.6127	4.5592	7.0630	22.3607	774.5967	0.1520	0.6732
1130	6.8442	6.9027	4.5592	7.0630	21.6987	729.4110	0.1548	0.6529
1050	6.3446	6.6372	4.5592	7.0630	20.9165	677.7721	0.1607	0.6265
940	5.7737	6.1945	4.5592	7.0630	19.7906	606.7674	0.1750	0.5020
840	5.6680	6.1263	4.5592	7.0630	18.7083	542.2177	0.1957	0.5331
740	5.1456	5.4868	4.5592	7.0630	17.5594	477.6479	0.2230	0.4700
650	5.2741	5.2232	4.5592	7.0630	16.4570	419.5732	0.2064	0.3967
575	3.2972	3.3872	4.5592	7.0630	15.4785	371.1609	0.2994	0.3100
520	2.0525	2.5393	4.5592	7.0630	14.7196	335.6586	0.2756	0.2490
445	2.5781	1.3274	4.5592	7.0630	13.6160	287.2463	0.1727	0.1107
380	-0.2490	0.3540	4.5592	7.0630	12.5831	245.2889	-0.3277	-0.0320
275	-1.3223	0.0000	4.5592	7.0630	10.7044	177.5117	0.0000	-0.4261

THEMIS PROJECT NUMBER 1 HIGH SPEED PADDLEWHEEL OCTOBER 1960

NUMBER OF BLADES= 6 D=5.0000 LITTLE D/D=0.1600 LITTLE D= 0.800 VB= 3.600

METHOD I

RPM	LITTLE N	LITTLE H	LAMBDA SUB 1	KT	KL	KQ	FROUDE NO.	SLIP	ETA	T	L	Q
1620	26.6667	1.7000	2.1031	0.0181	0.0000	0.0105	9.5295	0.8969	0.0092	0.7510	0.0000	0.1006
1520	25.2002	1.7000	2.1130	0.0177	0.0000	0.0129	8.9340	0.8980	0.0755	0.6470	0.0000	0.1963
1400	23.3333	1.7000	2.1179	0.0189	0.0000	0.0137	8.3384	0.8821	0.0816	0.6010	0.0000	0.1000
1180	19.6667	1.7000	2.1398	0.0245	0.0000	0.0178	7.0208	0.8602	0.0961	0.5540	0.0000	0.1679
1270	21.1667	1.7000	2.1299	0.0225	0.0000	0.0161	7.5641	0.8701	0.0900	0.5890	0.0000	0.1757
1040	17.3333	1.7000	2.1597	0.0296	0.0000	0.0212	6.1942	0.8413	0.1109	0.5220	0.0000	0.1550
930	15.5000	1.7000	2.1774	0.0329	0.0000	0.0252	5.5390	0.8226	0.1160	0.4620	0.0000	0.1472
860	14.3333	1.7000	2.1919	0.0375	0.0000	0.0289	5.1221	0.8081	0.1243	0.4500	0.0000	0.1447
790	13.1667	1.7000	2.2239	0.0399	0.0000	0.0326	4.7052	0.7911	0.1361	0.4040	0.0000	0.1292
710	11.8333	1.7000	2.2324	0.0453	0.0000	0.0379	4.2287	0.7676	0.1307	0.3700	0.0000	0.1292
625	10.4167	1.7000	2.2642	0.0493	0.0000	0.0431	3.7225	0.7360	0.1510	0.3120	0.0000	0.1137
535	8.9167	1.7000	2.3294	0.0496	0.0000	0.0427	3.1864	0.6916	0.1796	0.2310	0.0000	0.0027
425	7.0833	1.7000	2.3653	0.0628	0.0000	0.0656	2.5313	0.6117	0.1790	0.1700	0.0000	0.0091
250	4.1667	1.7000	2.6621	0.1144	0.0000	0.0918	1.4390	0.3396	0.4117	0.1160	0.0000	0.0367
190	3.1667	1.7000	2.6683	0.0393	0.0000	0.0635	1.1316	0.1315	0.2685	0.0230	0.0000	[illegible]
155	2.5833	1.7000	1.8646	-0.4158	0.0000	-0.0477	0.9232	-0.0646	4.6363	-0.1320	0.0000	-0.[illegible]77

METHOD II(VOLPICH)

RPM	(T*12**3)/(RHO*D**3)	(Q*12**4)/(RHO*D**4)	VA	VA/SQRT(D/12)	SQRT(ND/12)	NSQRT(D/12)	ETA	EFFECTIVE SLIP
1620	5.3597	3.0974	2.1316	3.3022	25.8199	1032.7956	0.0092	0.0772
1520	4.6175	3.3629	2.1316	3.3922	25.0000	968.2458	0.0755	0.0600
1400	4.2992	3.3974	2.1316	3.3022	24.1523	903.6961	0.0816	0.8307
1180	3.9538	2.8761	2.1316	3.3022	22.1736	761.6867	0.0961	0.8335
1270	4.2736	3.2085	2.1316	3.3022	23.0036	819.7015	0.0900	0.8453
1040	3.7111	2.6549	2.1316	3.3022	20.8167	671.3171	0.1109	0.8111
930	3.2972	2.5221	2.1316	3.3022	19.6850	600.3124	0.1160	0.7000
860	3.2116	2.4779	2.1316	3.3022	18.9297	555.1276	0.1243	0.7716
790	2.8833	2.2124	2.1316	3.3022	18.2436	509.9428	0.1361	0.7513
710	2.6426	2.2124	2.1316	3.3022	17.1990	458.3030	0.1387	0.7233
625	2.2267	1.9459	2.1316	3.3022	16.1374	403.4350	0.1510	0.6057
535	1.6485	1.4159	2.1316	3.3022	14.9324	345.3418	0.1796	0.6320
425	1.2704	1.3717	2.1316	3.3022	13.3073	274.3363	0.1790	0.5370
250	0.8279	0.6637	2.1316	3.3022	10.2062	161.3743	0.4116	0.2142
190	0.1641	0.2655	2.1316	3.3022	8.8976	122.6445	0.2685	-0.0339
155	-1.1562	-2.1327	2.1316	3.3022	8.0364	100.0521	4.6360	-0.2074

THEMIS PROJECT NUMBER 1 HIGH SPEED PADDLEWHEEL OCTOBER 1960

NUMBER OF BLADES= 6 D=5,0000 LITTLE D/D=0,1600 LITTLE D= 0,000 VA= 4,600

METHOD I

RPM	LITTLE N	LITTLE H	LAMBDA SUB 1	KT	KL	KQ	FROUDE NO,	SLIP	ETA	T	L	Q
1610	26,8333	1,7022	0,1310	0,0253	0,0002	0,0167	9,5891	0,8690	0.0093	1,0620	0,0000	0,2919
1430	23,8333	1,7000	0,1475	0,0272	0,0000	0,0222	8,5170	0,8525	0.0900	0,9010	0,0000	0,3074
1670	27,8333	1,7022	0,1263	0,0225	0,0002	0,0164	9,9465	0,8737	0.0862	1,0160	0,0000	0,3100
1250	20,8333	1,7022	0,1657	0,0333	0,0002	0,0250	7,4450	0,8313	0.1124	0,8430	0,0000	0,2635
1120	18,6667	1,7022	0,1883	0,0375	0,0000	0,0297	6,6787	0,8117	0.1210	0,7620	0,0000	0,2494
930	15,5000	1,7022	0,2267	0,0494	0,0000	0,0385	5,3390	0,7733	0.1456	0,6930	0,0000	0,2247
860	14,3333	1,7020	0,2452	0,0510	0,0000	0,0423	5,1221	0,7548	0.1551	0,6120	0,0000	0,2015
740	12,3333	1,7022	0,2849	0,0527	0,0020	0,0475	4,4874	0,7151	0.1521	0,4500	0,0000	0,1757
660	11,0000	1,7002	0,3195	0,0529	0,0000	0,0544	3,9329	0,6805	0.1554	0,3740	0,0000	0,1602
565	9,4167	1,7022	0,3732	0,0566	0,0000	0,0623	3,3651	0,6268	0.1696	0,2930	0,0000	0,1343
430	7,1667	1,7022	0,4924	0,0527	0,0000	0,0889	2,5611	0,5096	0.2226	0,2420	0,0000	0,1111
330	5,5000	1,7022	0,6392	0,1042	0,0000	0,1123	1,9655	0,3610	0.2963	0,1840	0,0000	0,0827
275	4,5833	1,7022	0,7667	0,0348	0,0000	0,0937	1,6379	0,2333	0.3497	0,1940	0,0000	0,0475
227	3,7833	1,7022	0,9289	0,0419	0,0000	0,0668	1,3520	0,0711	0.2913	0,0350	0,0000	0,0232
222	3,3333	1,7022	1,2543	-0,1700	0,0000	0,0896	1,1912	-0,0543	-9.8626	-0,1160	0,0000	0,0026

METHOD II(VOLPIC-)

RPM	(T*12**3)/(RHO*D**3)	(Q*12**4)/(RHO*D**4)	VA	VA/SQRT(D/12)	SQRT(ND/12)	NSQRT(D/12)	ETA	EFFECTIVE SLIP
1612	7,5793	5,2202	2,7237	4,2195	25,9805	1839.2505	0,0093	0,8441
1432	6,4323	5,2655	2,7237	4,2195	24,4097	[illegible]23.0610	0,0900	0,8245
1672	7,2517	5,3298	2,7237	4,2195	26,3787	1877.9884	0,0862	0,8497
1252	6,2163	4,5133	2,7237	4,2195	22,8218	886.8715	0,1124	0,7992
1122	5,4362	4,2236	2,7237	4,2195	21,6225	722.9569	0,1210	0,7759
932	4,9454	3,8496	2,7237	4,2195	19,6850	600.3124	0,1456	0,7301
862	4,3477	3,4514	2,7237	4,2195	18,9297	555.1276	0,1551	0,7001
742	3,2116	3,0259	2,7237	4,2195	17,5594	477.6679	0,1521	0,6600
662	2,6492	2,7434	2,7237	4,2195	16,5831	426.0252	0,1554	0,6197
565	2,0911	2,3079	2,7237	4,2195	15,3433	364.7059	0,1696	0,5557
432	1,7271	1,9227	2,7237	4,2195	13,3853	277.5638	0,2225	0,4162
332	1,3132	1,4159	2,7237	4,2195	11,7260	213.0141	0,2963	0,2393
275	0,7422	0,8136	2,7237	4,2195	10,7044	177.5117	0,3497	0,0072
227	2,2495	0,3952	2,7237	4,2195	9,7254	146.5279	0,2913	-0,1050
272	-2,8279	0,0442	2,7237	4,2195	9,1287	129.8994	-9,8621	-0,2951

THEMIS PROJECT NUMBER 1 HIGH SPEED PADDLEWHEEL OCTOBER 1960

NUMBER OF BLADES= 6 D=5.0000 LITTLE D/D=0.1600 LITTLE D= 0.800 VS= 5.400

METHOD I

RPM	LITTLE N	LITTLE H	LAMBDA SUB 1	KT	KL	KQ	FROUDE NO.	SLIP	ETA	T	L	Q
1360	22.6667	1.7000	0.1828	0.0439	0.0000	0.0356	8.1001	0.8180	0.1124	1.3170	0.0000	0.4443
1220	20.3333	1.7000	0.2229	0.0527	0.0000	0.0426	7.2663	0.7971	0.1253	1.2710	0.0000	0.4200
1130	18.8333	1.7000	0.2190	0.0524	0.0000	0.0443	6.7302	0.7810	0.1296	1.0060	0.0000	0.3823
1040	17.3333	1.7000	0.2390	0.0632	0.0000	0.0529	6.1942	0.7620	0.1478	1.1090	0.0000	0.3720
990	16.5000	1.7000	0.2500	0.0596	0.0000	0.0484	5.8964	0.7500	0.1540	0.9470	0.0000	0.3203
920	15.3333	1.7000	0.2752	0.0580	0.0000	0.0529	5.3604	0.7250	0.1589	0.7620	0.0000	0.2893
820	13.6667	1.7000	0.3219	0.0508	0.0000	0.0569	4.8839	0.6981	0.1340	0.5540	0.0000	0.2503
710	11.8333	1.7000	0.3486	0.0550	0.0000	0.0667	4.2287	0.6514	0.1438	0.4500	0.0000	0.2273
625	10.4167	1.7000	0.3962	0.0504	0.0000	0.0783	3.7225	0.6040	0.1477	0.3700	0.0000	0.2067
525	8.4167	1.7000	0.4921	0.0670	0.0000	0.1064	3.0078	0.5099	0.1542	0.2770	0.0000	0.1034
410	6.8333	1.7000	0.6037	0.1144	0.0000	0.1092	2.4419	0.3963	0.3165	0.3130	0.0000	0.1240
385	6.4167	1.7000	0.6429	0.0674	0.0000	0.1032	2.2930	0.3571	0.2100	0.1620	0.0000	0.1633
355	5.9167	1.7000	0.6973	0.0452	0.0000	0.1701	2.1144	0.3027	0.1560	0.0020	0.0000	0.0052
330	5.5000	1.7000	0.7521	0.0200	0.0000	0.0878	1.9655	0.2499	0.0000	0.0000	0.0000	0.0646
265	4.4167	1.7000	0.9341	-0.0711	0.0000	0.0327	1.5783	0.0659	-1.0164	-0.0810	0.0000	0.0155
230	3.8333	1.7000	1.0762	-0.0693	0.0000	0.0000	1.3699	-0.0762	0.0000	-0.2310	0.0000	0.0000

METHOD II(VOLPICH)

RPM	(T*12**3)/(RHO*D**3)	(Q*12**4)/(RHO*D**4)	VA	VA/SQRT(D/12)	SQRT(ND/12)	NSQRT(D/12)	ETA	EFFECTIVE SLIP
1360	9.3992	7.6107	3.1973	4.9533	23.8048	877.8762	0.1124	0.7833
1220	9.2729	7.3452	3.1973	4.9533	22.5462	787.5066	0.1253	0.7585
1130	7.7506	6.5487	3.1973	4.9533	21.6987	720.4110	0.1296	0.7392
1040	7.9147	6.3717	3.1973	4.9533	20.8167	671.3171	0.1478	0.7167
990	6.7586	5.4868	3.1973	4.9533	20.3181	639.0423	0.1540	0.7024
920	5.4382	4.9558	3.1973	4.9533	19.3649	588.8475	0.1589	0.6726
820	3.9536	4.4248	3.1973	4.9533	18.4842	529.3077	0.1349	0.4486
710	3.2116	3.8938	3.1973	4.9533	17.1998	458.3030	0.1430	0.5853
625	2.6426	3.5399	3.1973	4.9533	16.1374	403.4350	0.1477	0.5289
525	1.9769	3.1416	3.1973	4.9533	14.5257	325.0761	0.1542	0.4165
410	2.2267	2.1239	3.1973	4.9533	13.0723	264.6539	0.3164	0.2813
385	1.1562	1.7699	3.1973	4.9533	12.6696	240.5164	0.2100	0.2346
355	0.6566	1.4602	3.1973	4.9533	12.1621	229.1515	0.1560	0.1699
330	0.0000	1.1062	3.1973	4.9533	11.7260	213.0141	0.0000	0.1671
265	-0.5781	0.2655	3.1973	4.9533	10.5279	171.0560	-1.0160	-0.1120
230	-1.6486	0.0000	3.1973	4.9533	9.7895	140.4644	0.0000	-0.2812

THEMIS PROJECT NUMBER 1 HIGH SPEED PADDLEWHEEL OCTOBER 1968

NUMBER OF BLADES= 6 D=5.0020 LITTLE D/D=0.1600 LITTLE D= 0.800 V0= 7.700

METHOD I

RPM	LITTLE N	LITTLE H	LAMBDA SUB 1	KT	KL	KQ	FROUDE NO.	SLIP	ETA	T	L	Q
1220	20.3333	1.7000	0.2893	0.0488	0.0000	0.0555	7.2863	0.7107	0.1272	1.1780	0.0000	0.5900
1110	18.5000	1.7000	0.3150	0.0508	0.0000	0.0645	6.6111	0.6820	0.1251	1.0150	0.0000	0.5373
7800	130.0000	1.7000	0.2453	0.0029	0.0000	0.0011	46.4565	0.9547	0.0189	0.9810	0.0000	0.4495
920	15.3333	1.7000	0.3936	0.0673	0.0000	0.0849	5.4795	0.6164	0.1521	0.9240	0.0000	0.4057
760	12.6667	1.7000	0.4644	0.0864	0.0000	0.1085	4.5265	0.5350	0.1848	0.8090	0.0000	0.4237
680	11.3333	1.7000	0.5190	0.0942	0.0000	0.1290	4.0501	0.4810	0.1892	0.7050	0.0000	0.4030
530	8.8333	1.7000	0.6659	0.0863	0.0000	0.0871	3.1967	0.3341	0.3290	0.3930	0.0000	0.1653
610	10.1667	1.7000	0.5786	0.1092	0.0000	0.1110	3.6331	0.4214	0.2843	0.6500	0.0000	0.2790
480	8.0000	1.7000	0.7353	0.0275	[illegible]	0.0631	2.8589	0.2647	0.1623	0.1040	0.0000	0.0902
440	7.3333	1.7000	0.8222	-0.0073	[illegible]	0.0434	2.6206	0.1970	-0.0676	-0.0230	0.0000	0.0500
375	6.2500	1.7000	0.9412	-0.0601	0.0000	0.0217	2.2335	0.2500	-1.2999	-0.1370	0.0000	0.0207
310	5.1667	1.7000	1.1386	-0.1777	[illegible]	0.0002	1.8463	-0.1386	12.7169	-0.2770	0.0000	0.0052

METHOD II(VOLPICH)

RPM	(T*12**3)/(RHO*D**3)	(Q*12**4)/(RHO*D**4)	VA	VA/SQRT(D/12)	SQRT(ND/12)	NSQRT(D/12)	ETA	EFFECTIVE SLIP
1220	8.4072	9.5576	4.5592	7.0638	22.5462	787.5066	0.1272	0.6556
1110	7.2439	9.2236	4.5592	7.0632	21.5058	716.5019	0.1251	0.6215
7800	6.4323	7.6992	4.5592	7.0630	57.0200	5034.8753	0.0189	0.9461
920	6.5944	8.3167	4.5592	7.0638	19.5789	593.0574	0.1521	0.5433
760	5.7737	7.2567	4.5592	7.0630	17.7951	490.5779	0.1847	0.4471
680	5.2315	6.9027	4.5592	7.0630	16.8325	438.9301	0.1892	0.3821
530	2.8749	2.8319	4.5592	7.0633	14.8605	342.1135	0.3290	0.7272
610	4.6963	4.7798	4.5592	7.0630	15.9426	393.7533	0.2843	0.4112
480	0.7422	1.6314	4.5592	7.0630	14.1421	339.0307	0.1623	0.1246
440	-0.1641	0.9735	4.5592	7.0632	13.5401	284.0100	-0.0676	0.0450
375	-0.9777	0.3543	4.5592	7.0630	12.5000	242.0615	-1.2990	-0.1205
310	-1.9769	0.2835	4.5592	7.0632	11.3652	200.1041	-12.7163	-0.3554

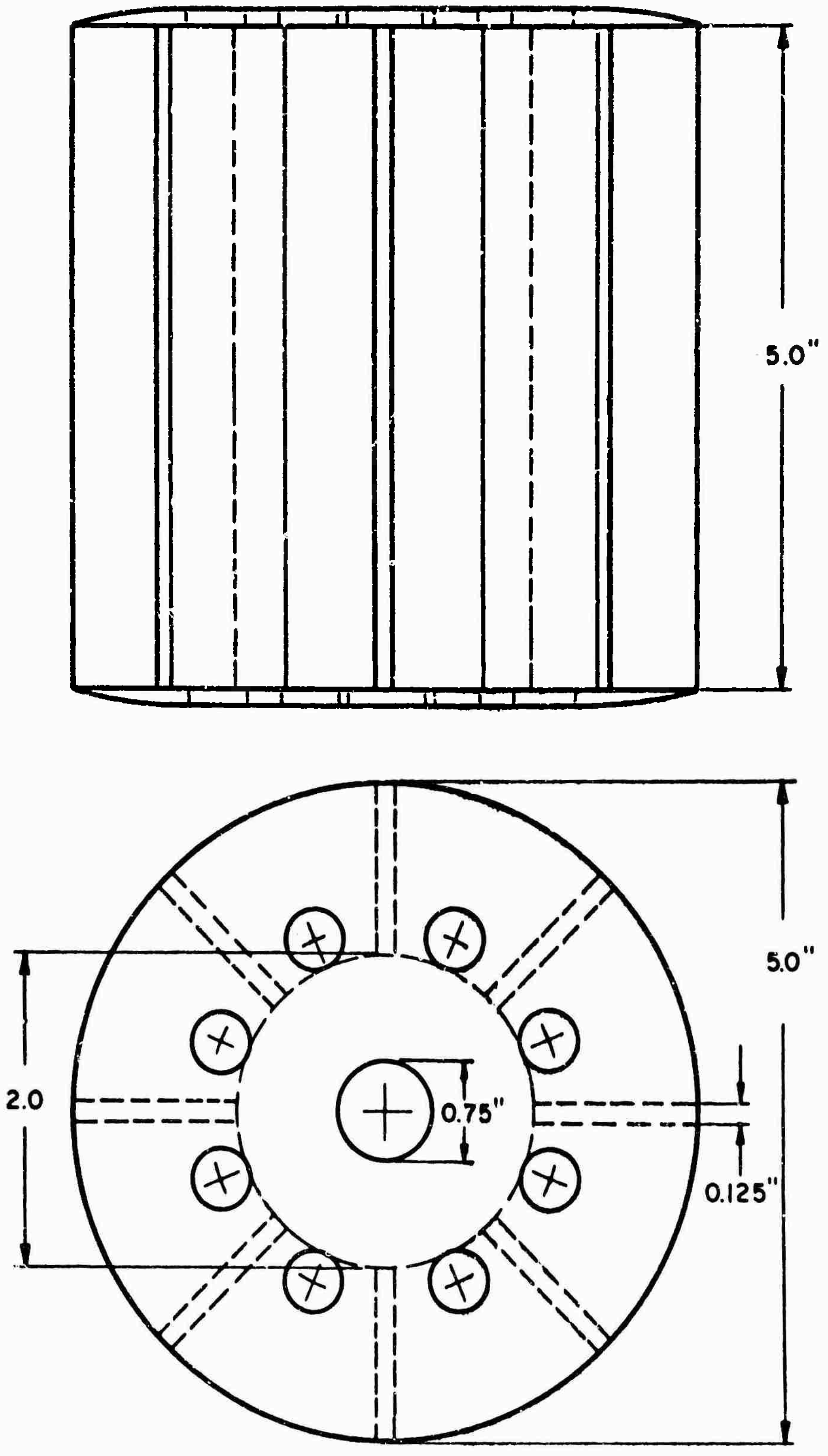

FIGURE 1. MODEL PADDLE WHEEL WITH FIXED RADIAL BLADES AND END PLATES

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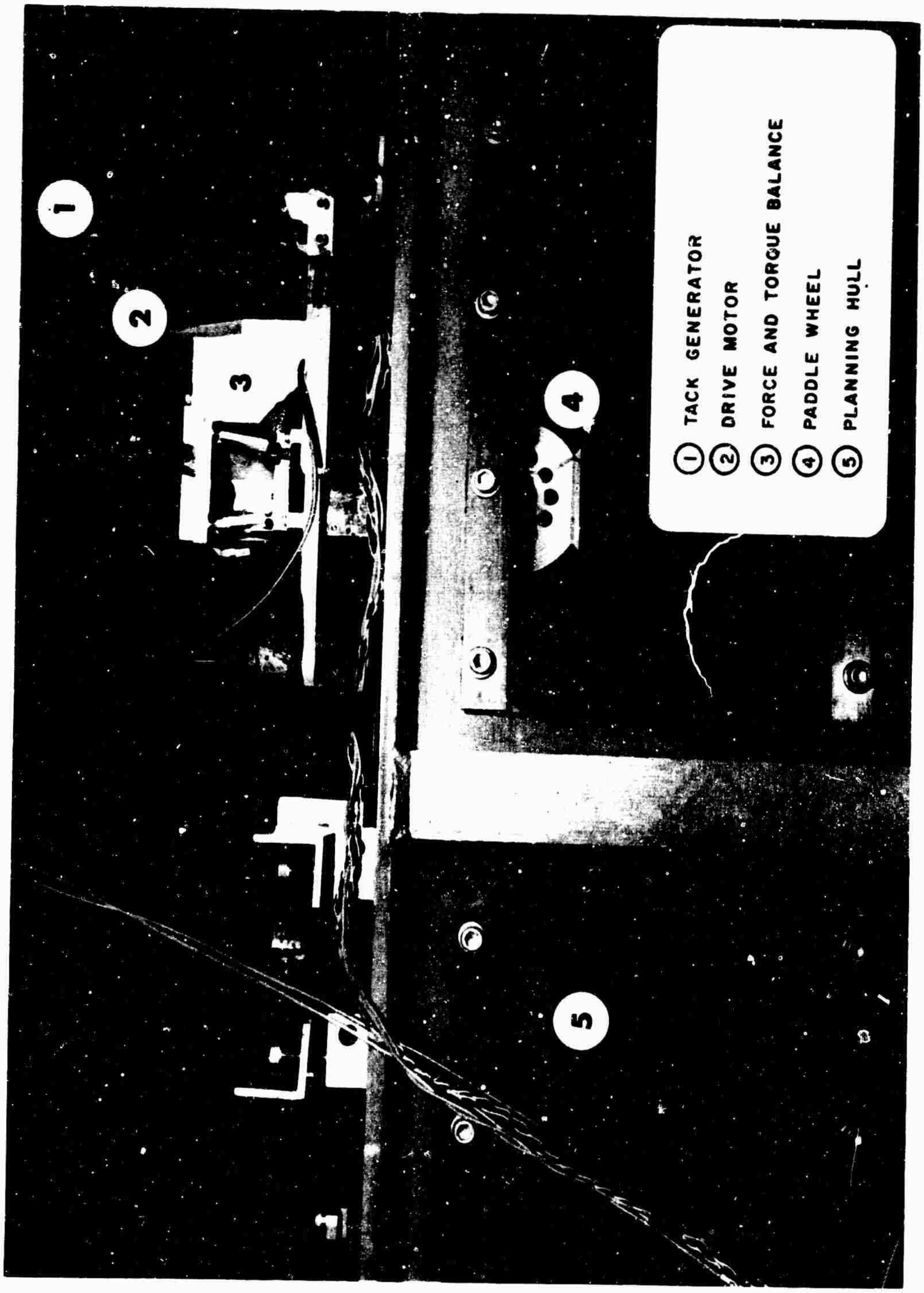


FIGURE 2. PADDLE WHEEL TEST ASSEMBLY INSTALLED IN WATER CHANNEL

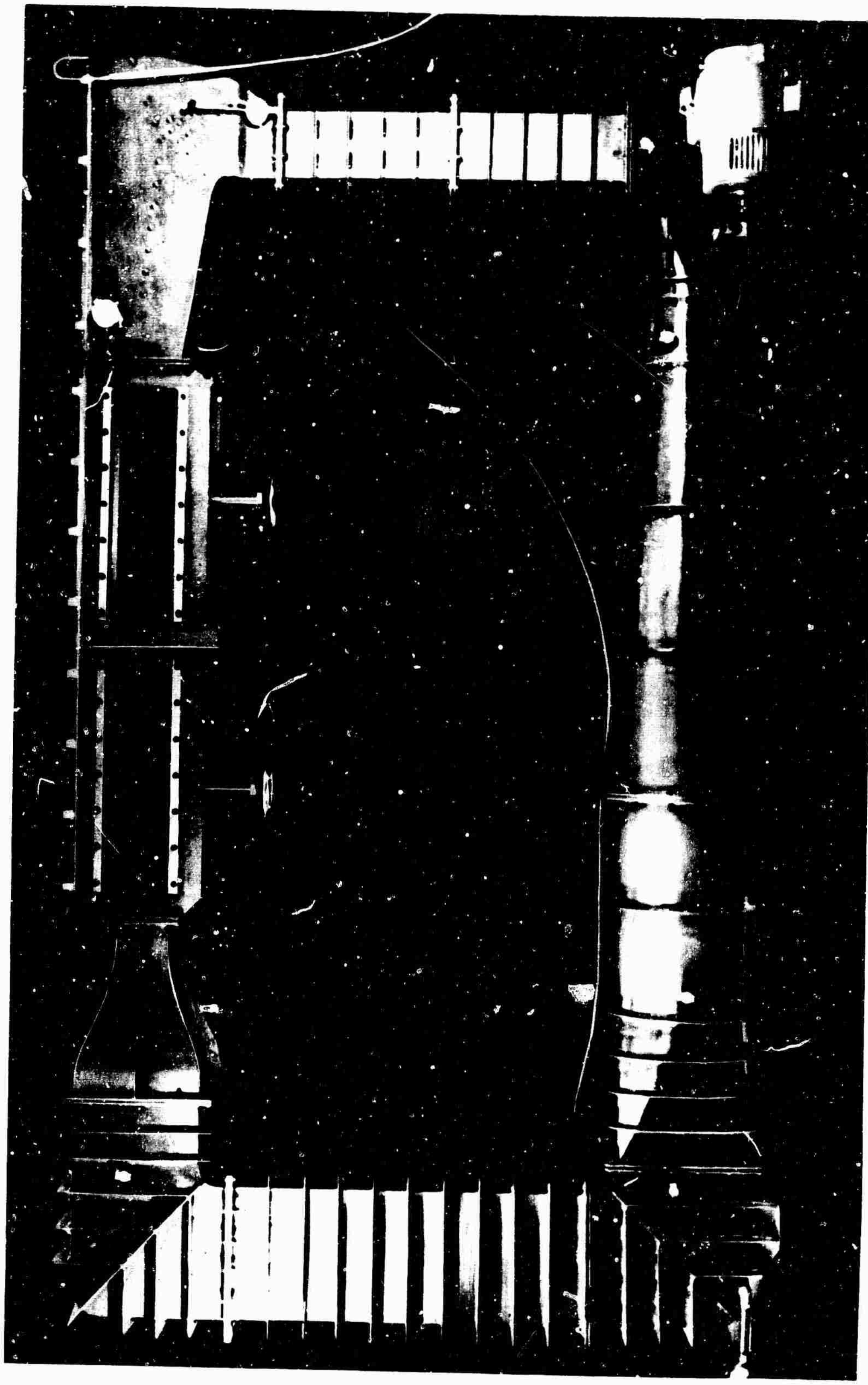


FIGURE 3. DAVIDSON LABORATORY FREE-SURFACE VARIABLE-PRESSURE WATER CHANNEL

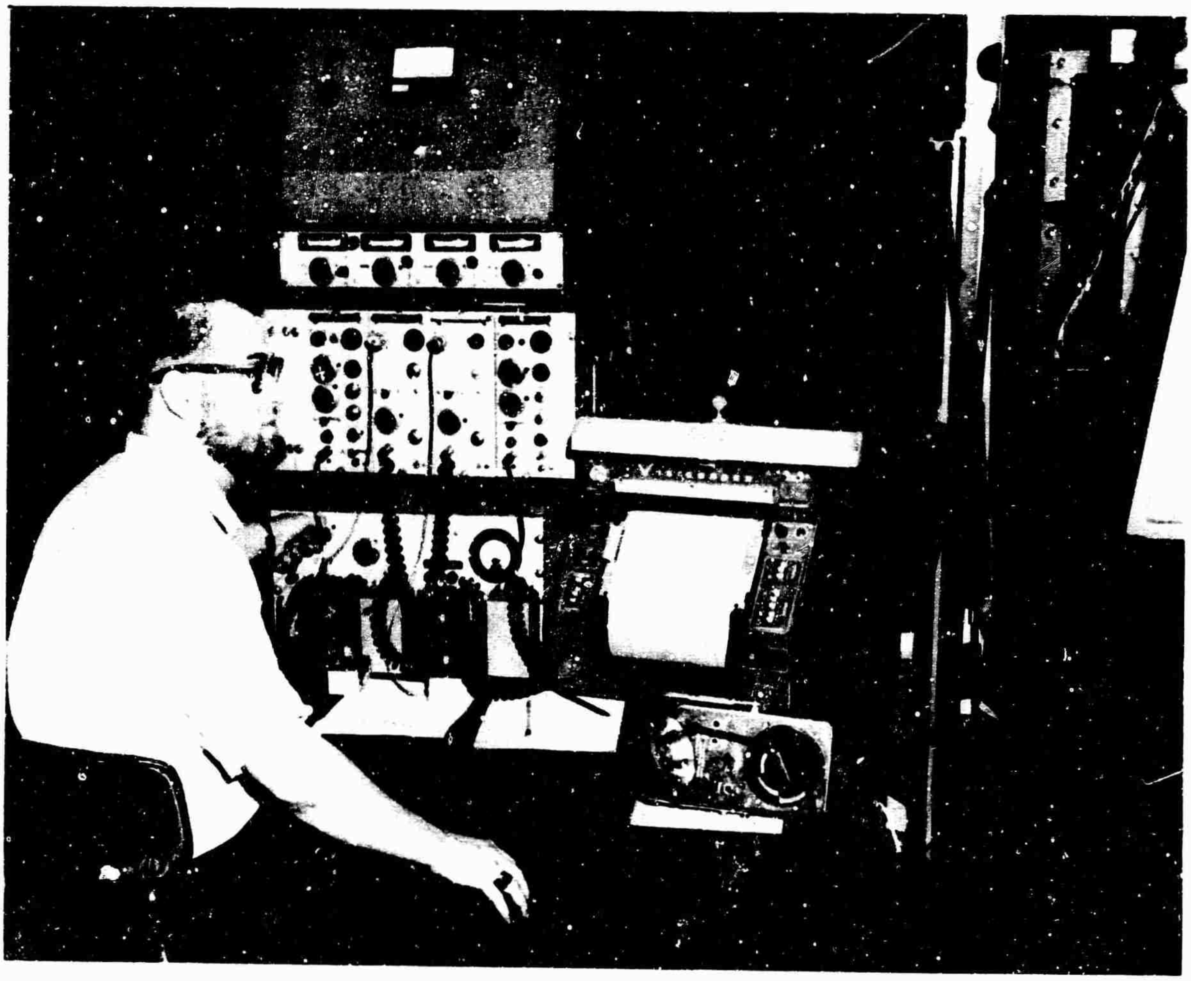


FIGURE 4. RECORDING EQUIPMENT FOR WHEEL THRUST AND TORQUE, AND WHEEL SPEED CONTROLLER

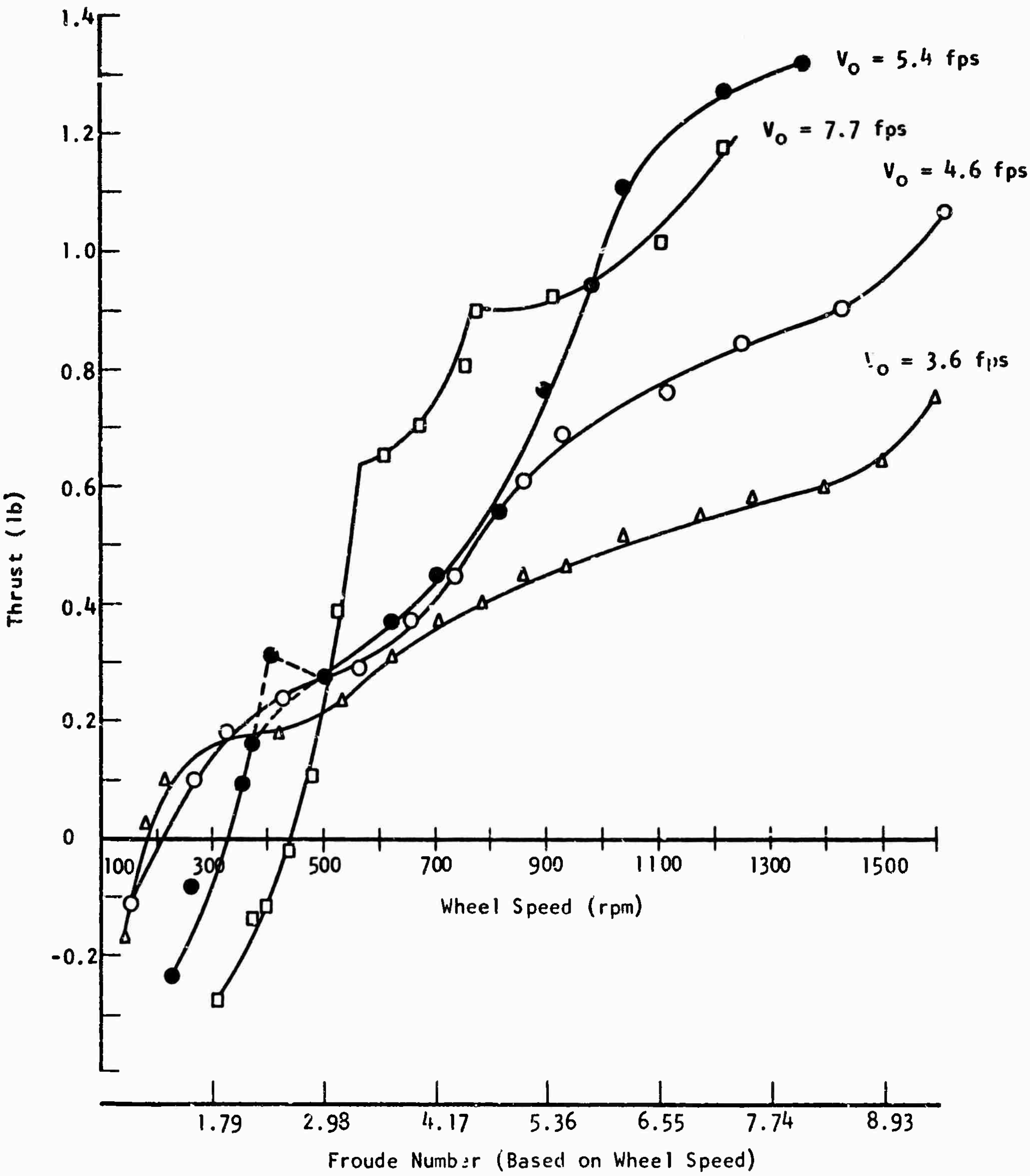


FIGURE 5. WHEEL THRUST VERSUS WHEEL SPEED FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 6-BLADE WHEEL WITH A BLADE IMMERSION DEPTH OF 0.80 INCH

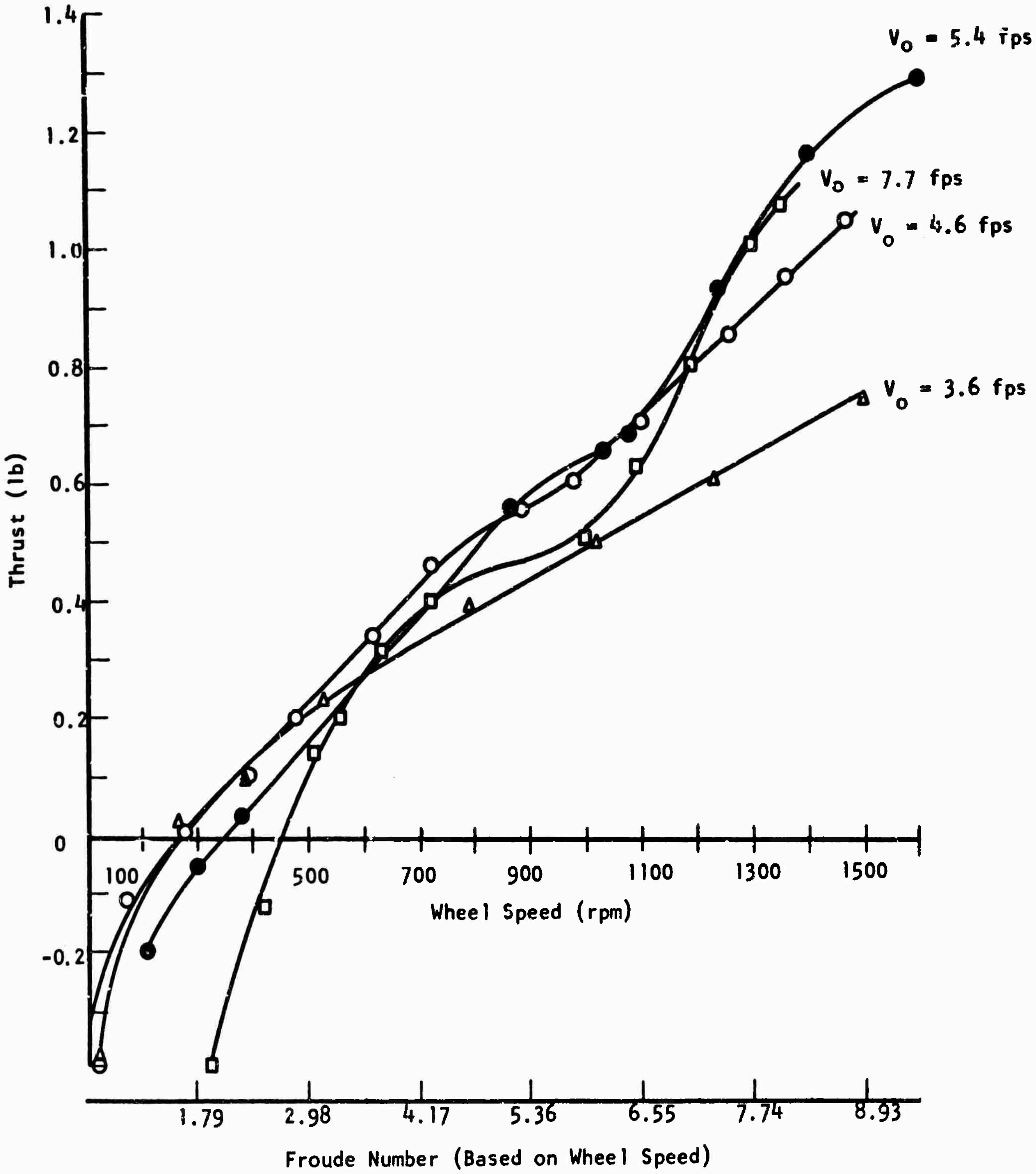


FIGURE 6. WHEEL THRUST VERSUS WHEEL SPEED FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 12-BLADE WHEEL WITH A BLADE IMMERSION DEPTH OF 0.80 INCH

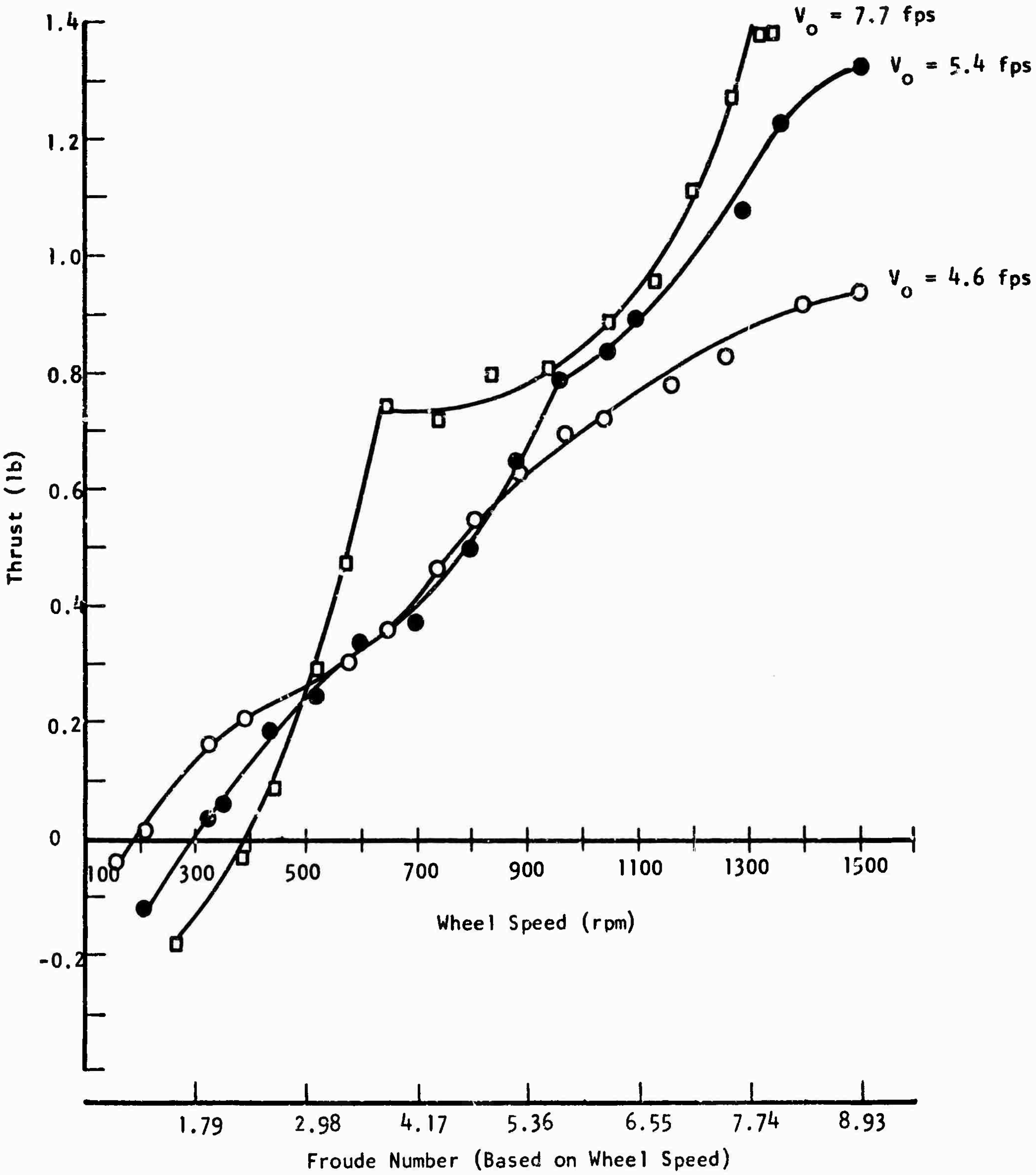


FIGURE 7. WHEEL THRUST VERSUS WHEEL SPEED FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 6-BLADE WHEEL WITH A BLADE IMMERSION DEPTH OF 0.50 INCH

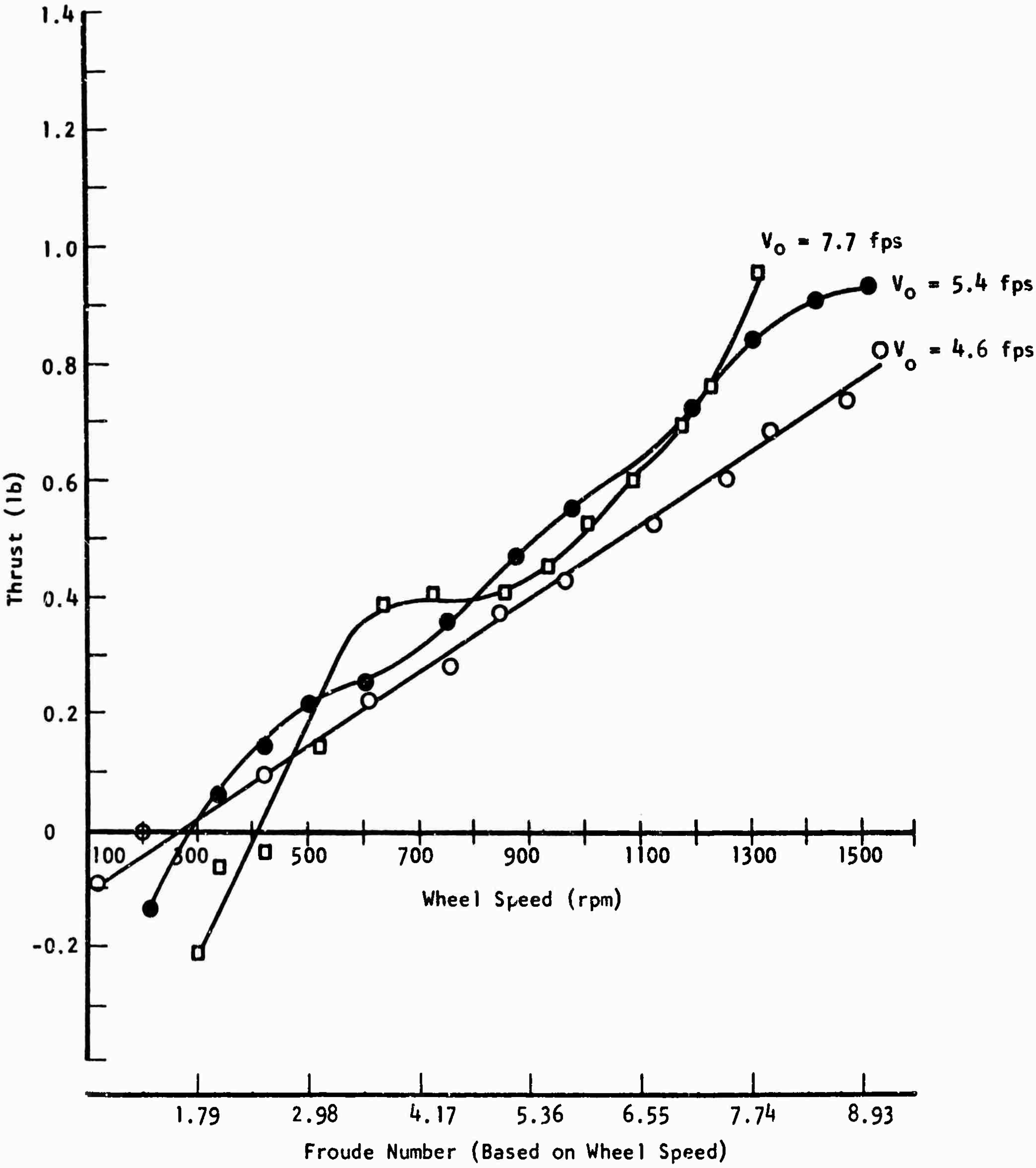


FIGURE 8. WHEEL THRUST VERSUS WHEEL SPEED FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 12-BLADE WHEEL WITH A BLADE IMMERSION DEPTH OF 0.50 INCH

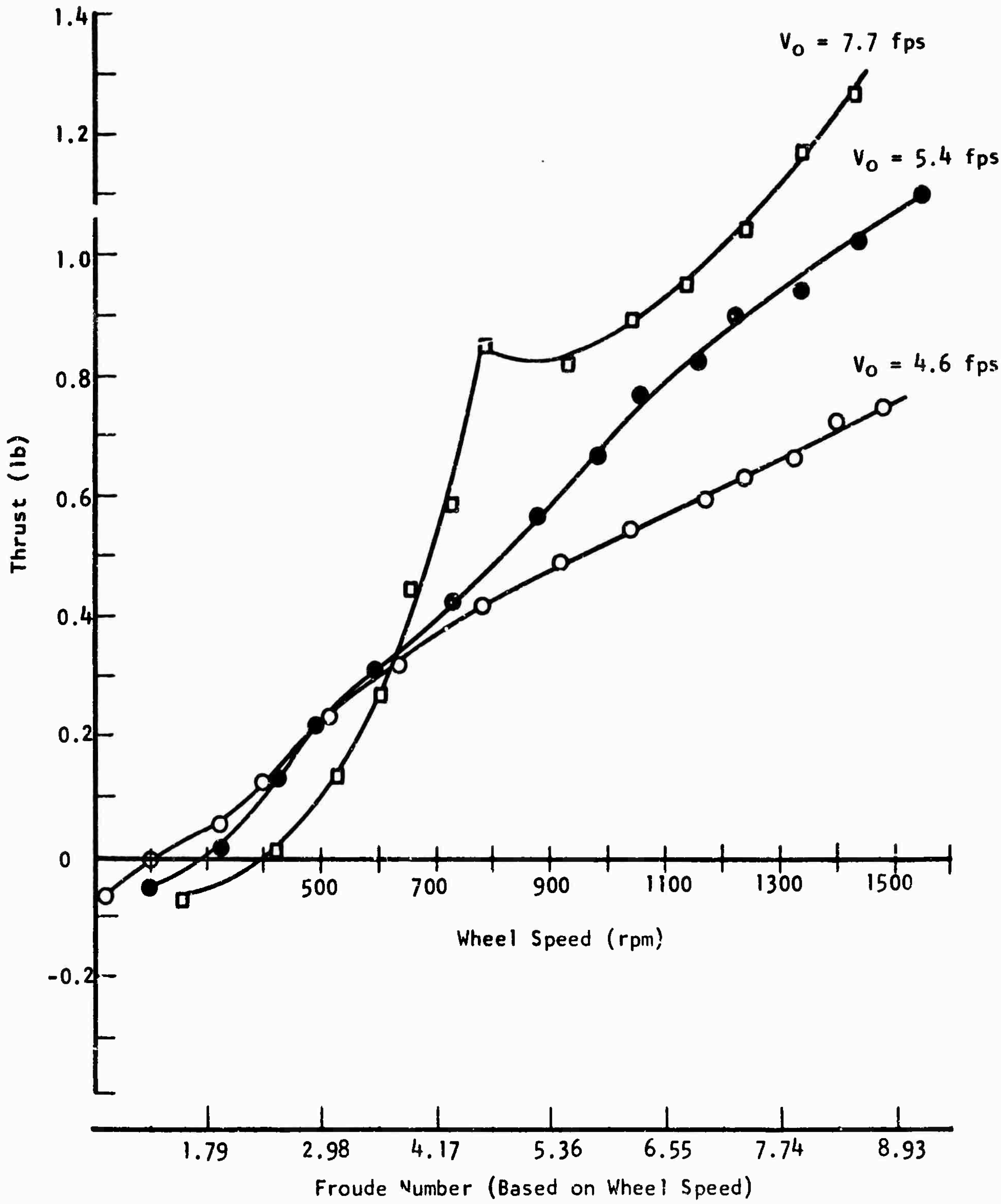


FIGURE 9. WHEEL THRUST VERSUS WHEEL SPEED FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 6-BLADE WHEEL WITH A BLADE IMMERSION DEPTH OF 0.30 INCH

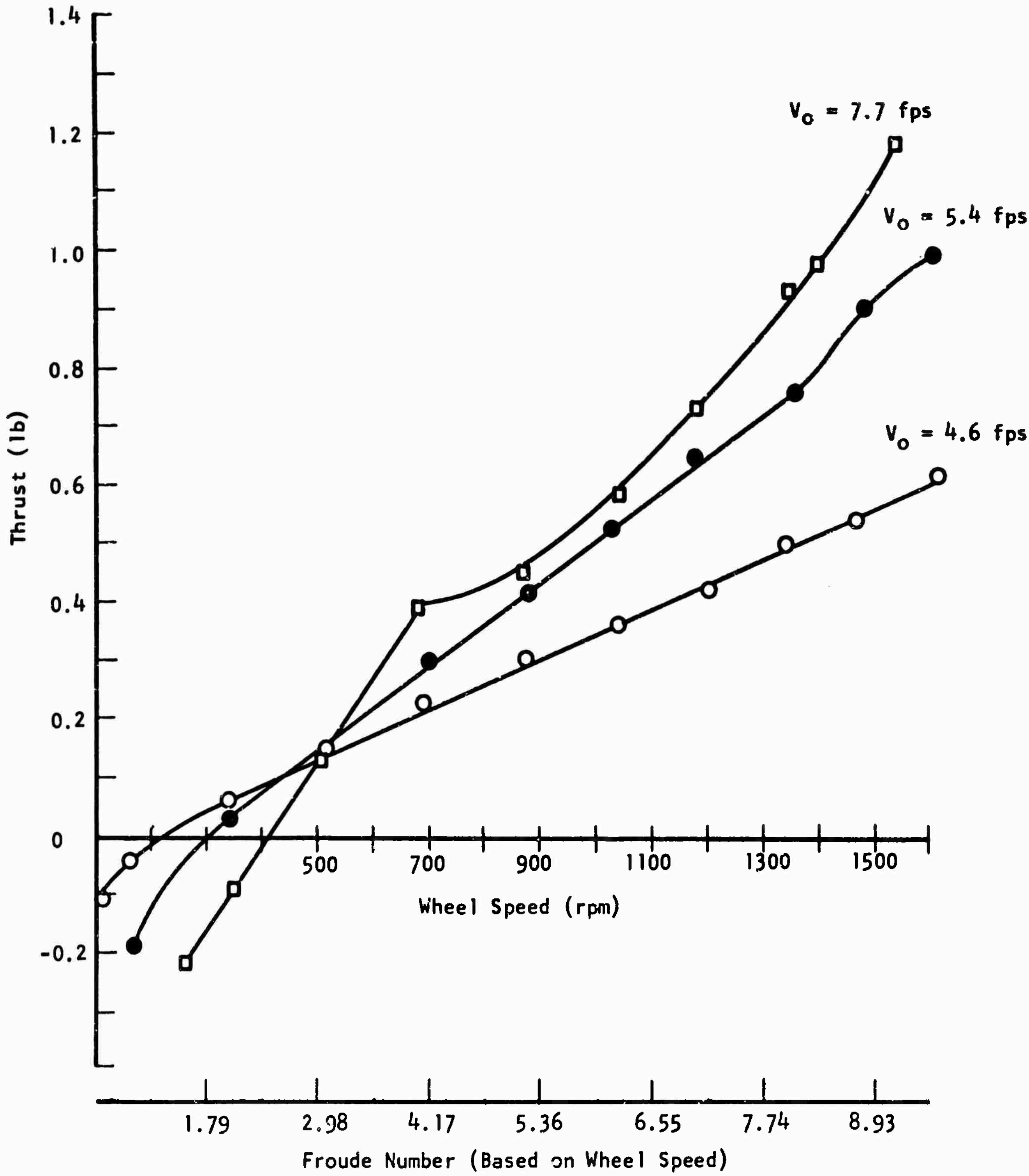


FIGURE 10. WHEEL THRUST VERSUS WHEEL SPEED FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 12-BLADE WHEEL WITH A BLADE IMMERSION DEPTH OF 0.30 INCH

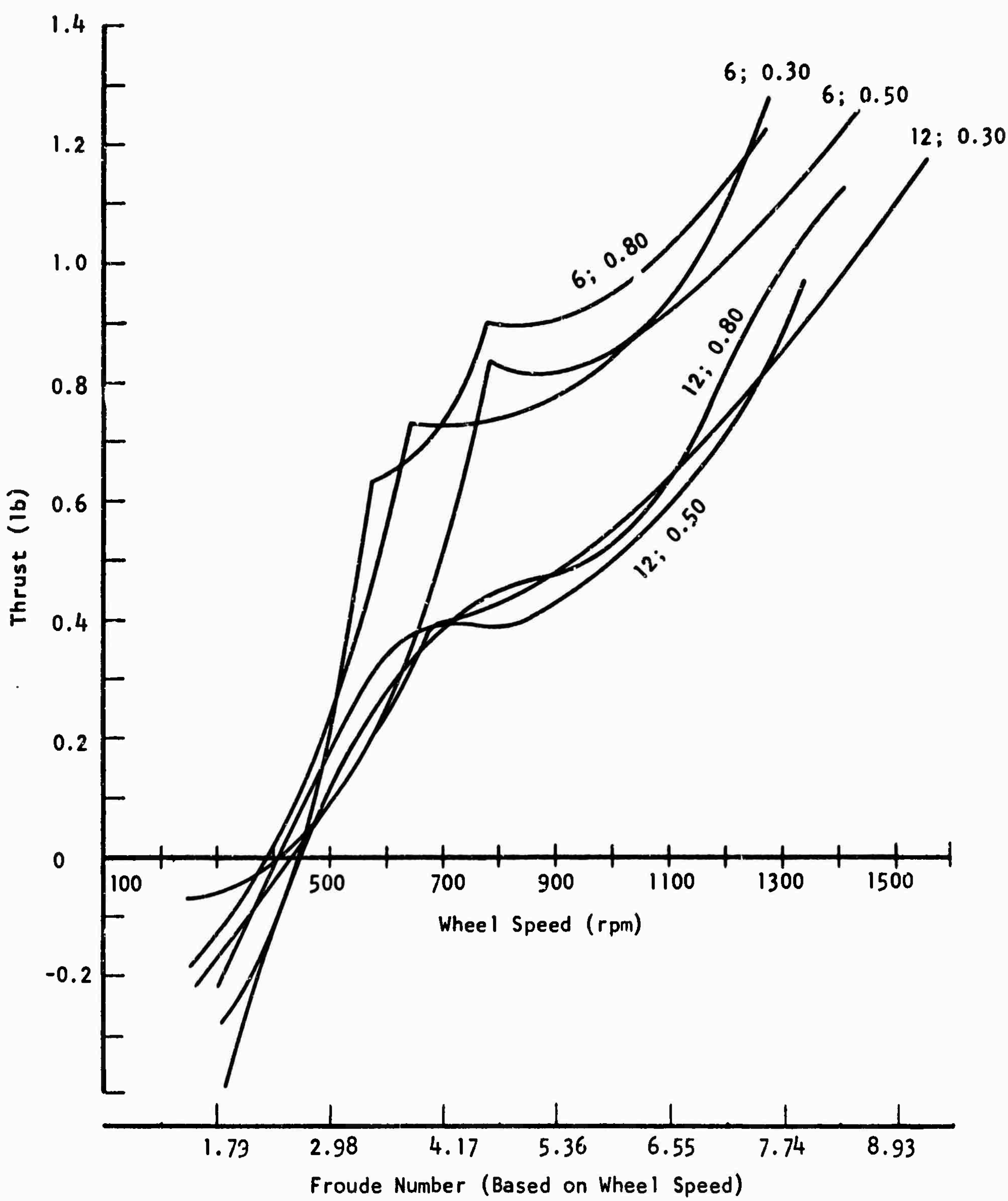


FIGURE 11. COMPOSITE OF DATA PRESENTED IN FIGURES 5 THROUGH 10: EFFECT OF NUMBER OF BLADES AND BLADE IMMERSION DEPTH ON WHEEL THRUST, FOR AN ADVANCE VELOCITY (V_o) OF 7.7 FPS (THE FIRST NUMBER BY EACH CURVE INDICATES THE NUMBER OF BLADES; THE SECOND, THE IMMERSION DEPTH IN INCHES)

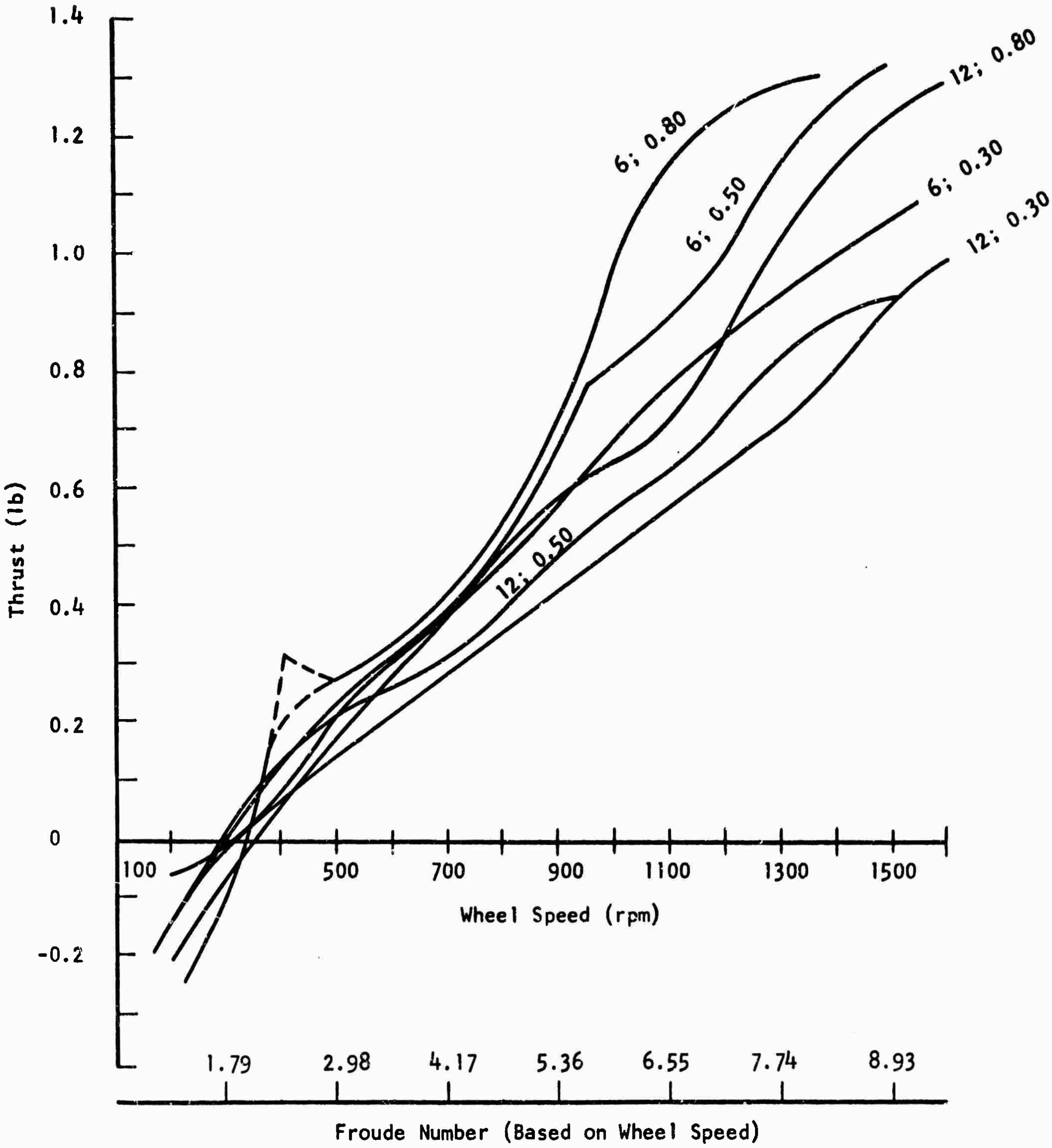


FIGURE 12. COMPOSITE OF DATA PRESENTED IN FIGURES 5 THROUGH 10: EFFECT OF NUMBER OF BLADES AND BLADE IMMERSION DEPTH ON WHEEL THRUST, FOR AN ADVANCE VELOCITY (V_o) OF 5.4 FPS (THE FIRST NUMBER BY EACH CURVE INDICATES THE NUMBER OF BLADES; THE SECOND, THE IMMERSION DEPTH IN INCHES)

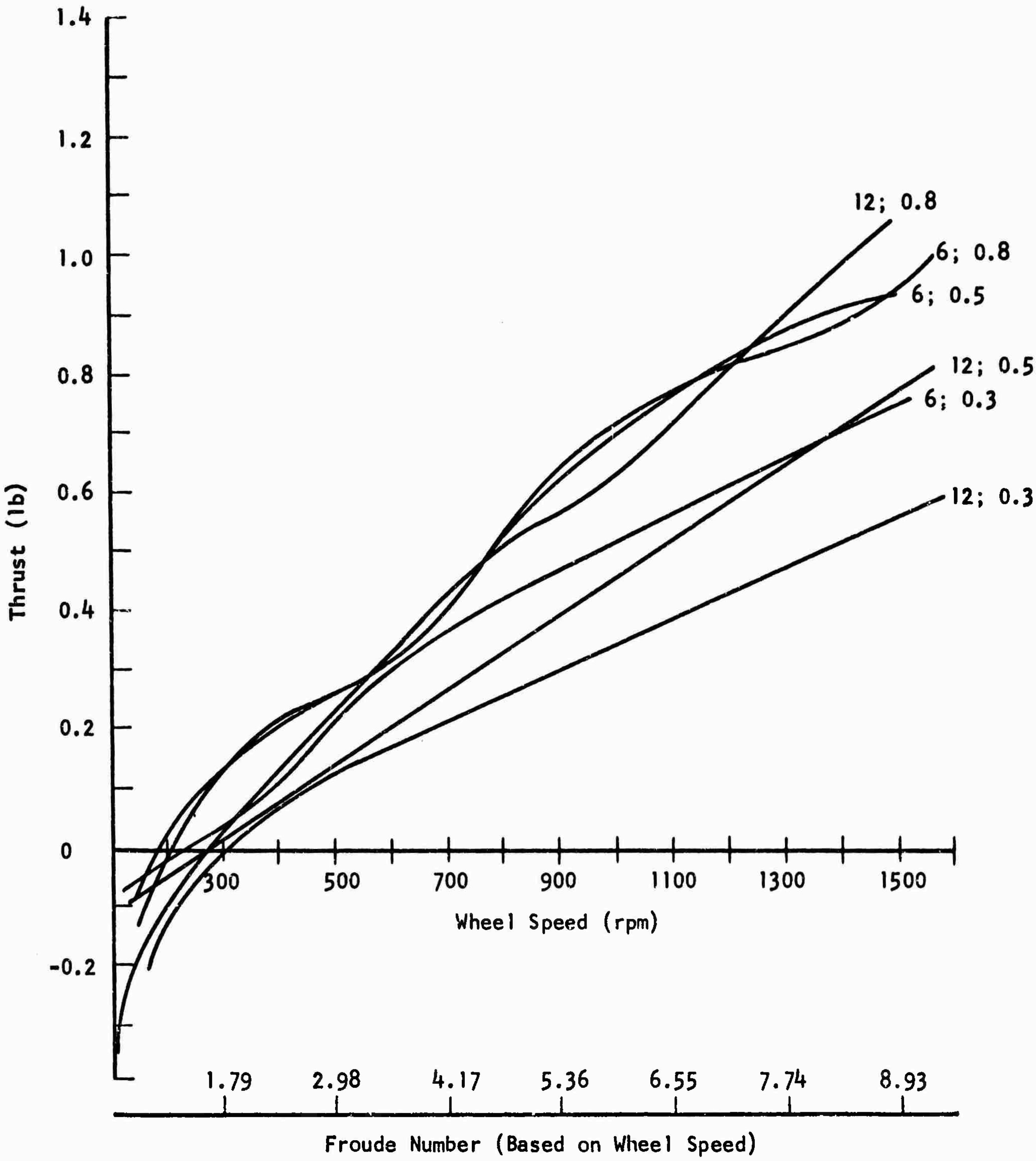


FIGURE 13. COMPOSITE OF DATA PRESENTED IN FIGURES 5 THROUGH 10: EFFECT OF NUMBER OF BLADES AND BLADE IMMERSION DEPTH ON WHEEL THRUST, FOR AN ADVANCE VELOCITY (V_o) OF 4.6 FPS (THE FIRST NUMBER BY EACH CURVE INDICATES THE NUMBER OF BLADES; THE SECOND, THE IMMERSION DEPTH IN INCHES)

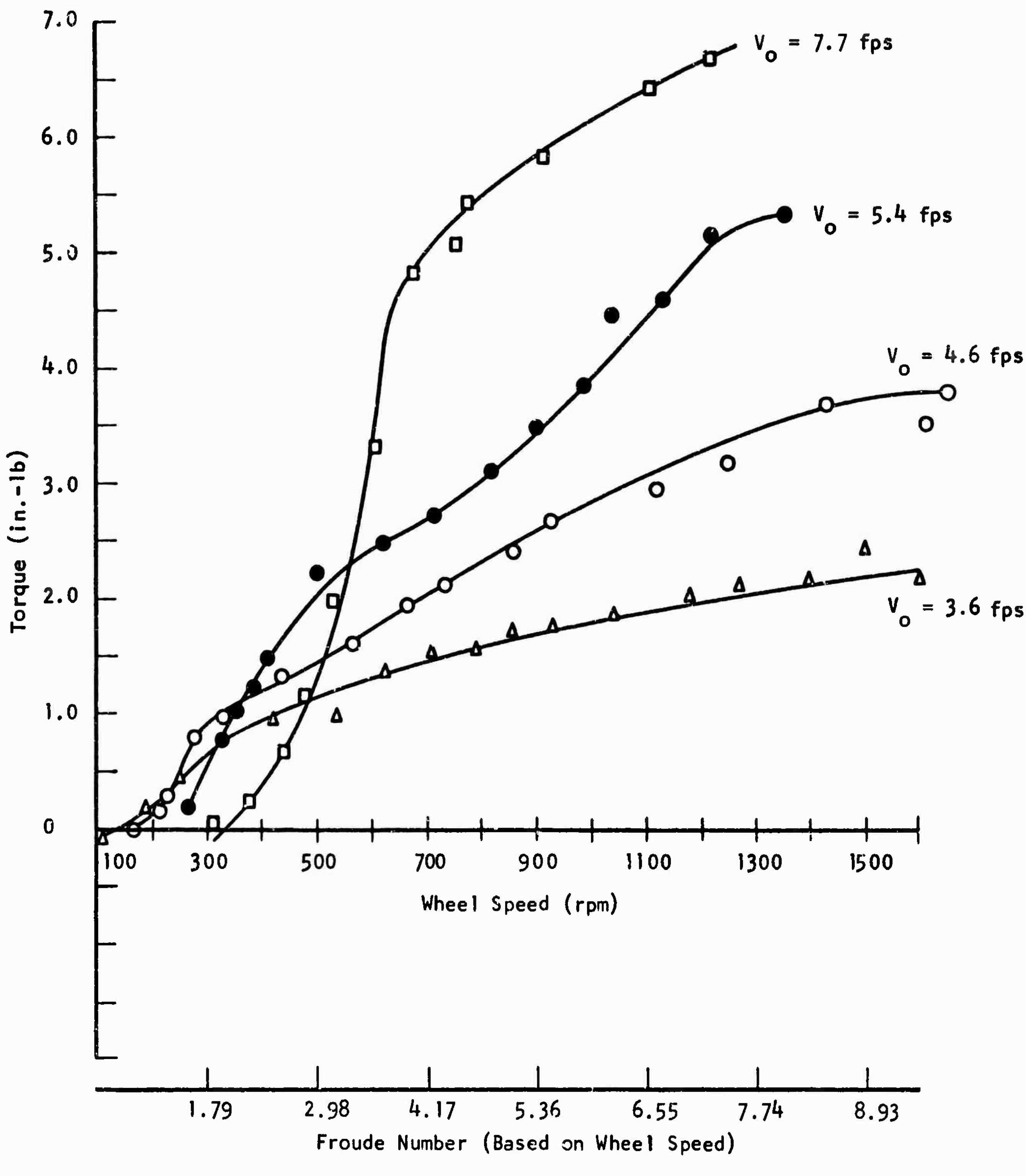


FIGURE 14. WHEEL TORQUE VERSUS WHEEL SPEED AND FROUDE NUMBER FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 6-BLADE WHEEL WITH A BLADE IMMERSION DEPTH OF 0.80 INCH

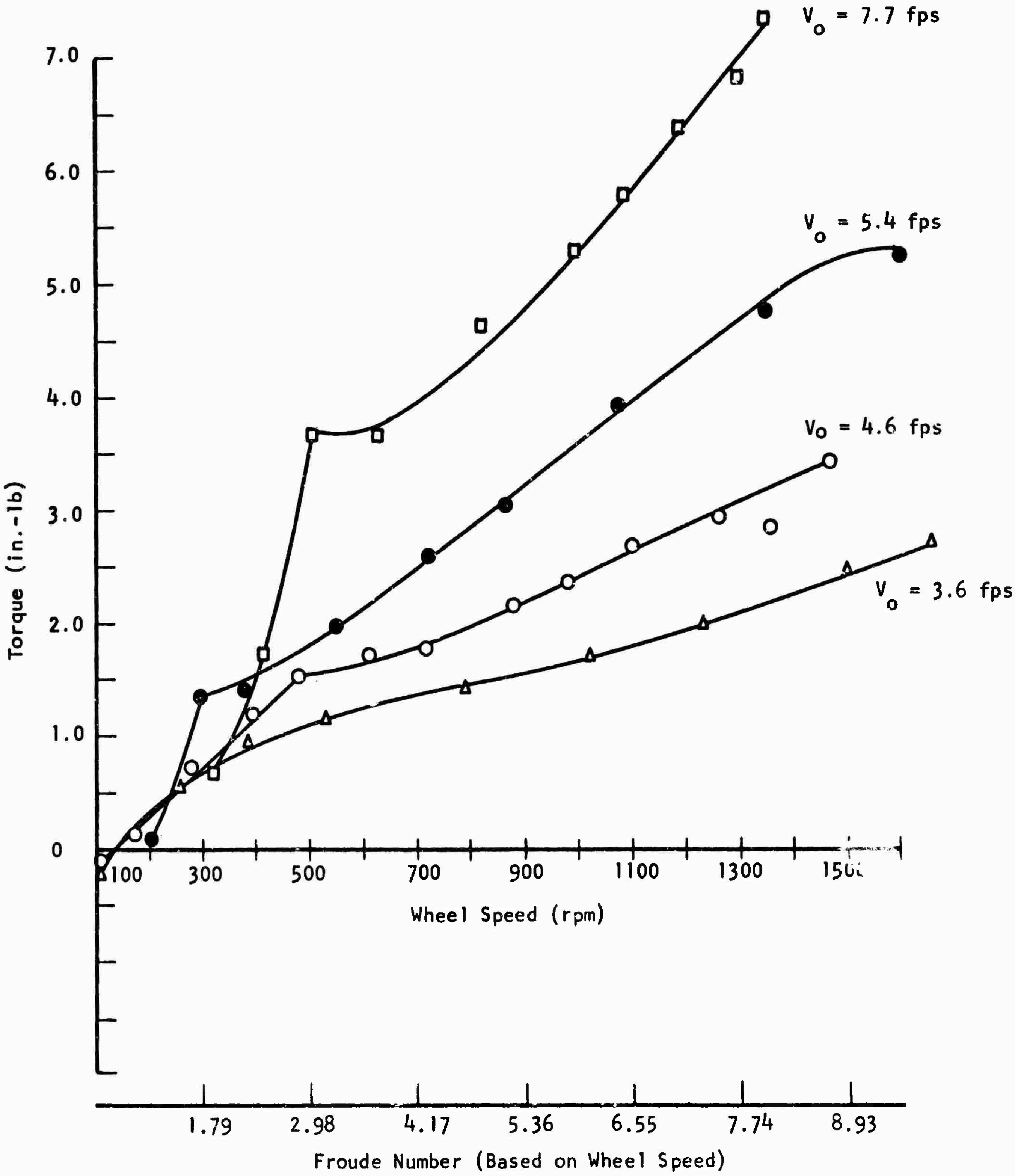


FIGURE 15. WHEEL TORQUE VERSUS WHEEL SPEED AND FROUDE NUMBER FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 12-BLADE WHEEL WITH A BLADE IMMERSION DEPTH OF 0.80 INCH

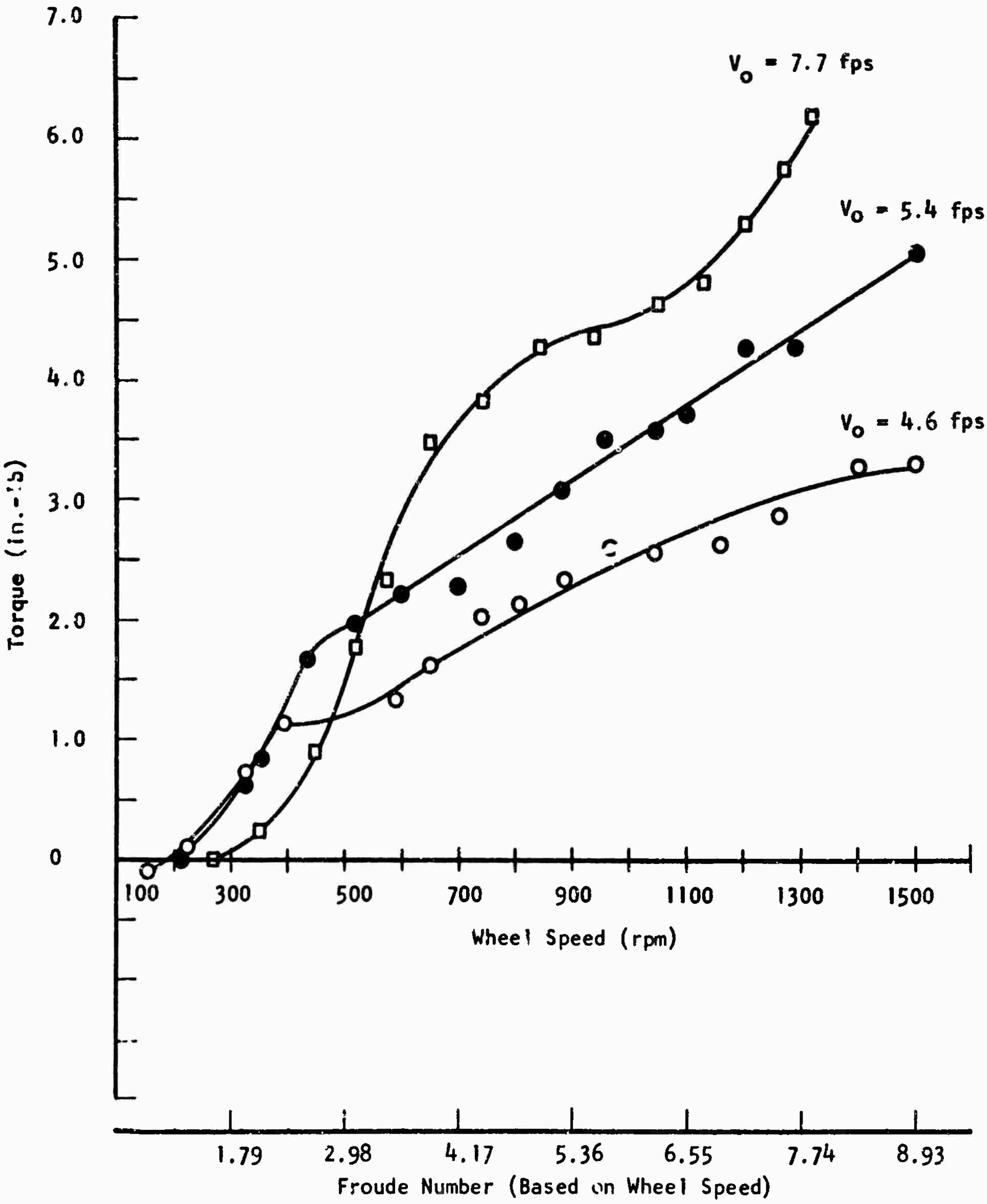


FIGURE 16. WHEEL TORQUE VERSUS WHEEL SPEED AND FROUDE NUMBER FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 6-BLADE WHEEL WITH A BLADE IMMERSION DEPTH OF 0.50 INCH

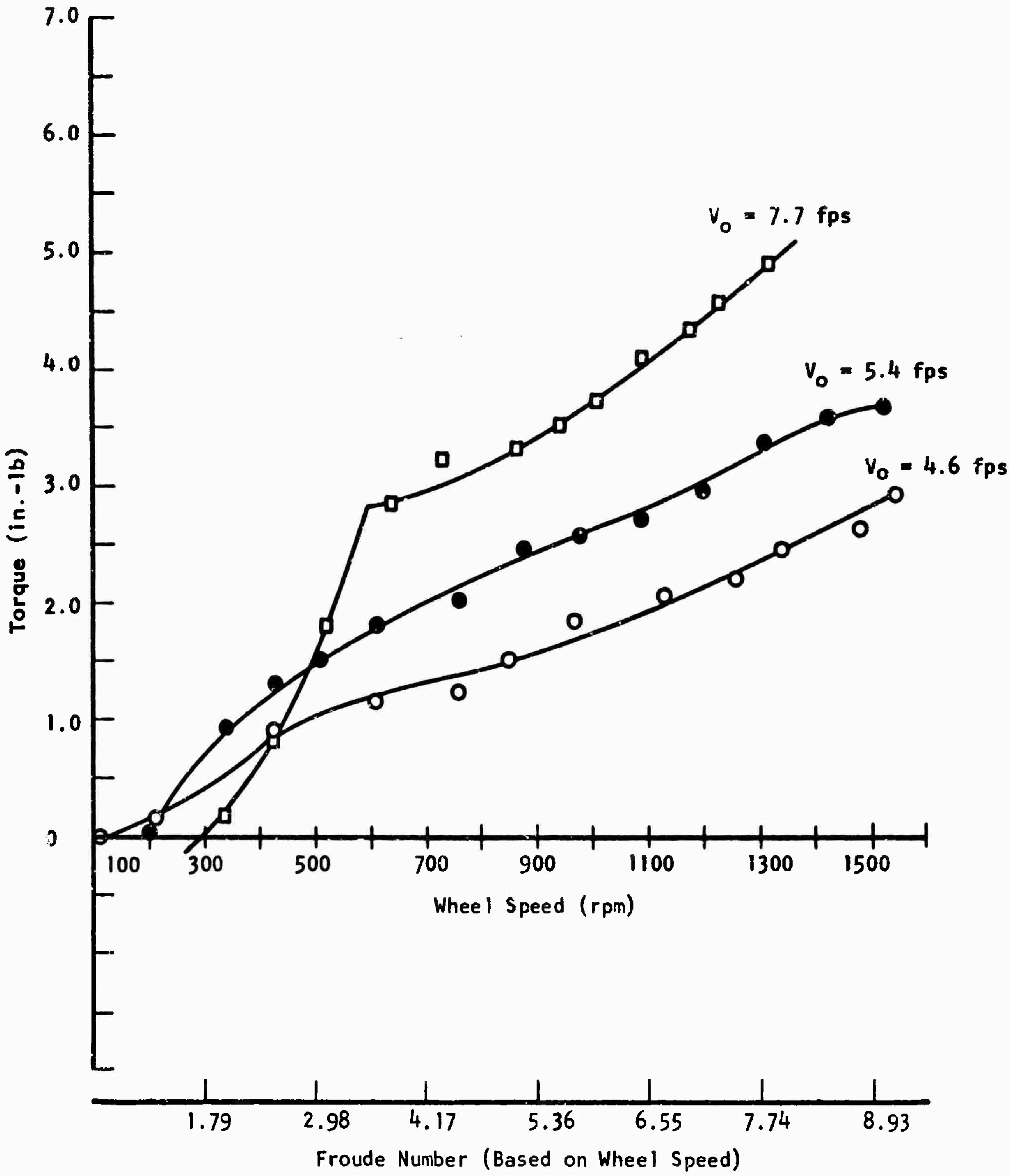


FIGURE 17. WHEEL TORQUE VERSUS WHEEL SPEED AND FROUDE NUMBER FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 12-BLADE WHEEL WITH A BLADE IMMERSION DEPTH OF 0.50 INCH

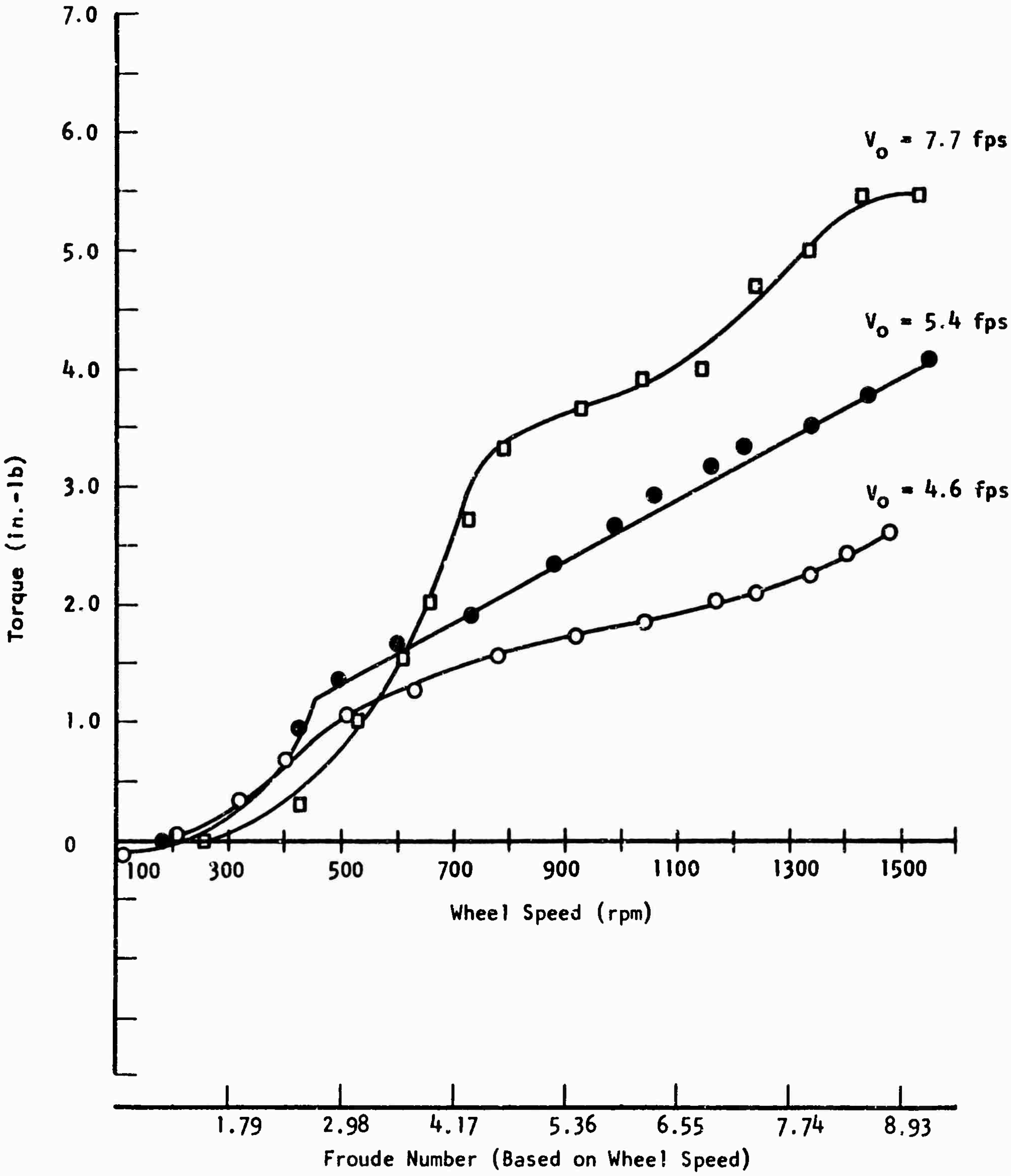


FIGURE 18. WHEEL TORQUE VERSUS WHEEL SPEED AND FROUDE NUMBER FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 6-BLADE WHEEL WITH A BLADE IMMERSION DEPTH OF 0.30 INCH

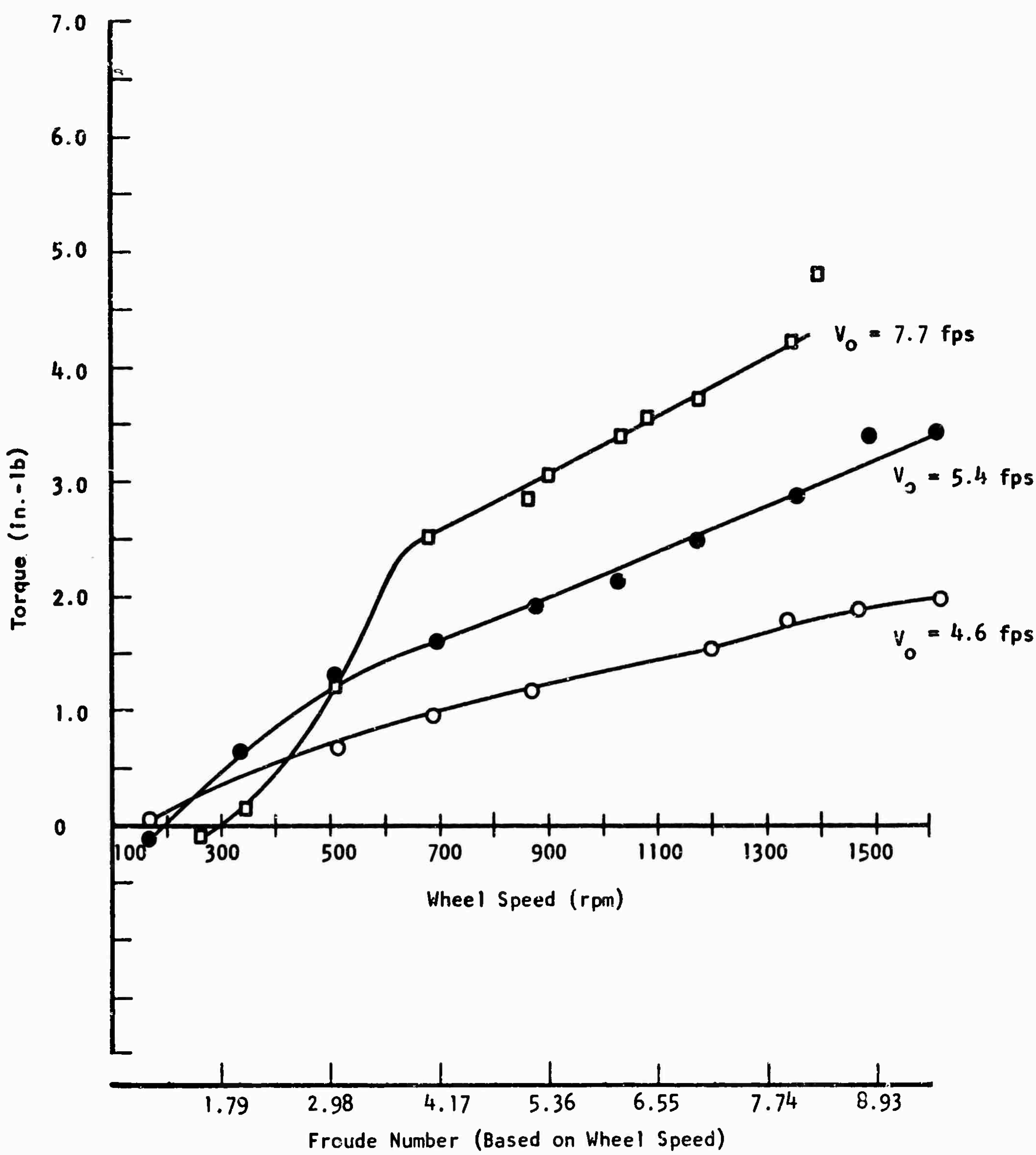


FIGURE 19. WHEEL TOPQUE VERSUS WHEEL RPM AND FROUDE NUMBER FOR VARIOUS ADVANCE VELOCITIES (V_O), FOR A 12-BLADE WHEEL WITH A BLADE IMMERSION DEPTH OF 0.30 INCH

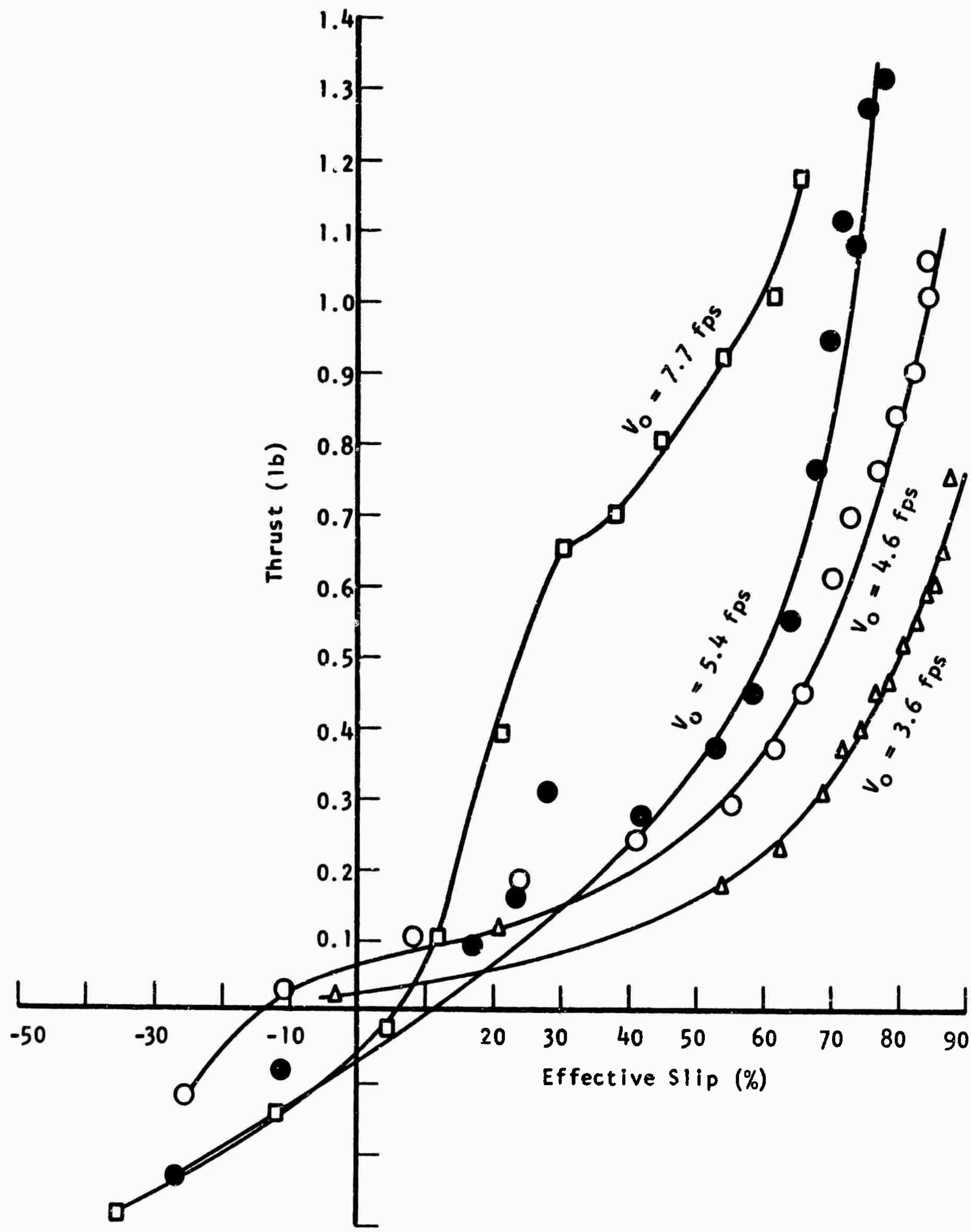


FIGURE 20. THRUST VERSUS EFFECTIVE SLIP FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 6-BLADE WHEEL AND A BLADE IMMERSION DEPTH OF 0.80 INCH

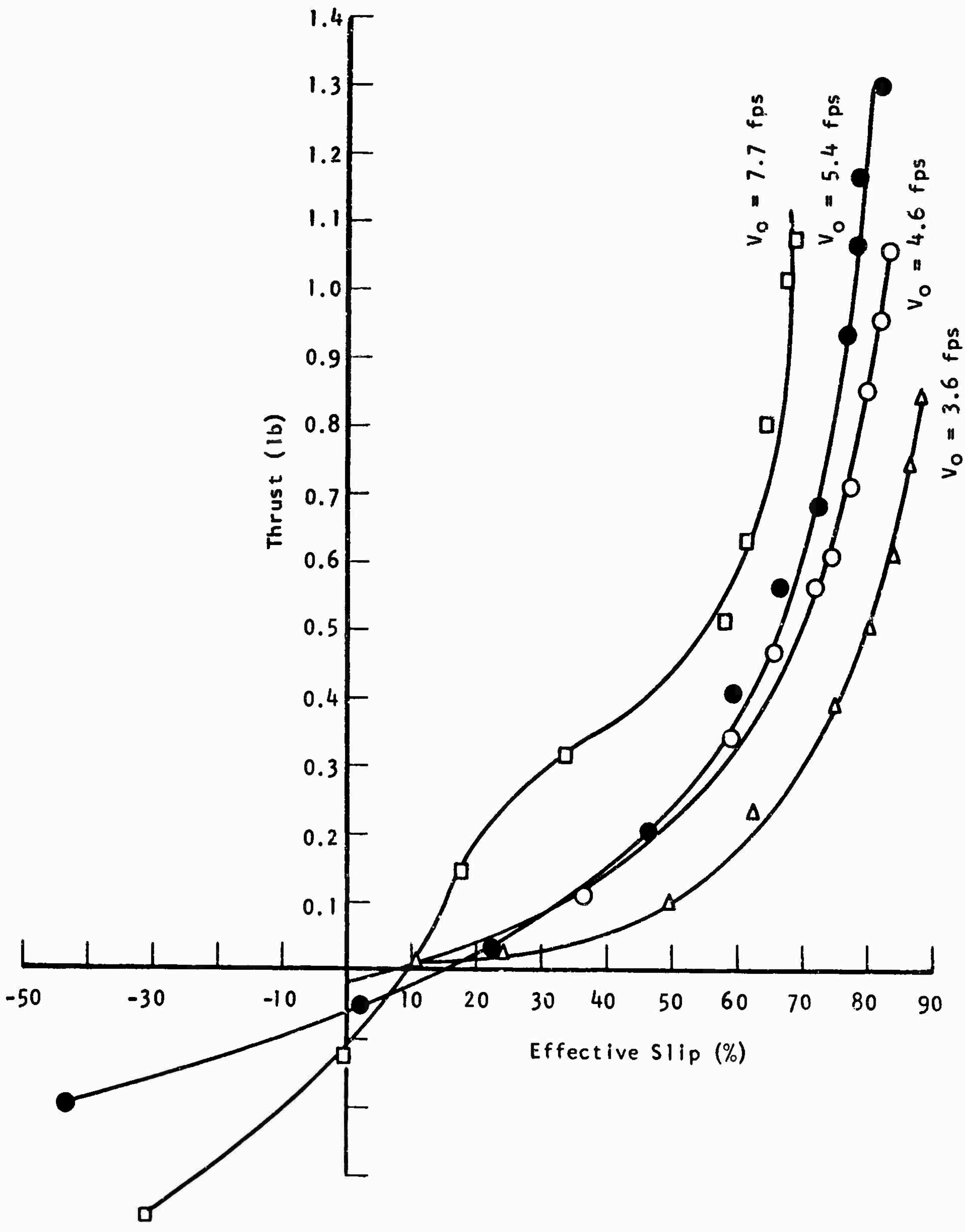


FIGURE 21. THRUST VERSUS EFFECTIVE SLIP FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 12-BLADE WHEEL AND A BLADE IMMERSION DEPTH OF 0.80 INCH

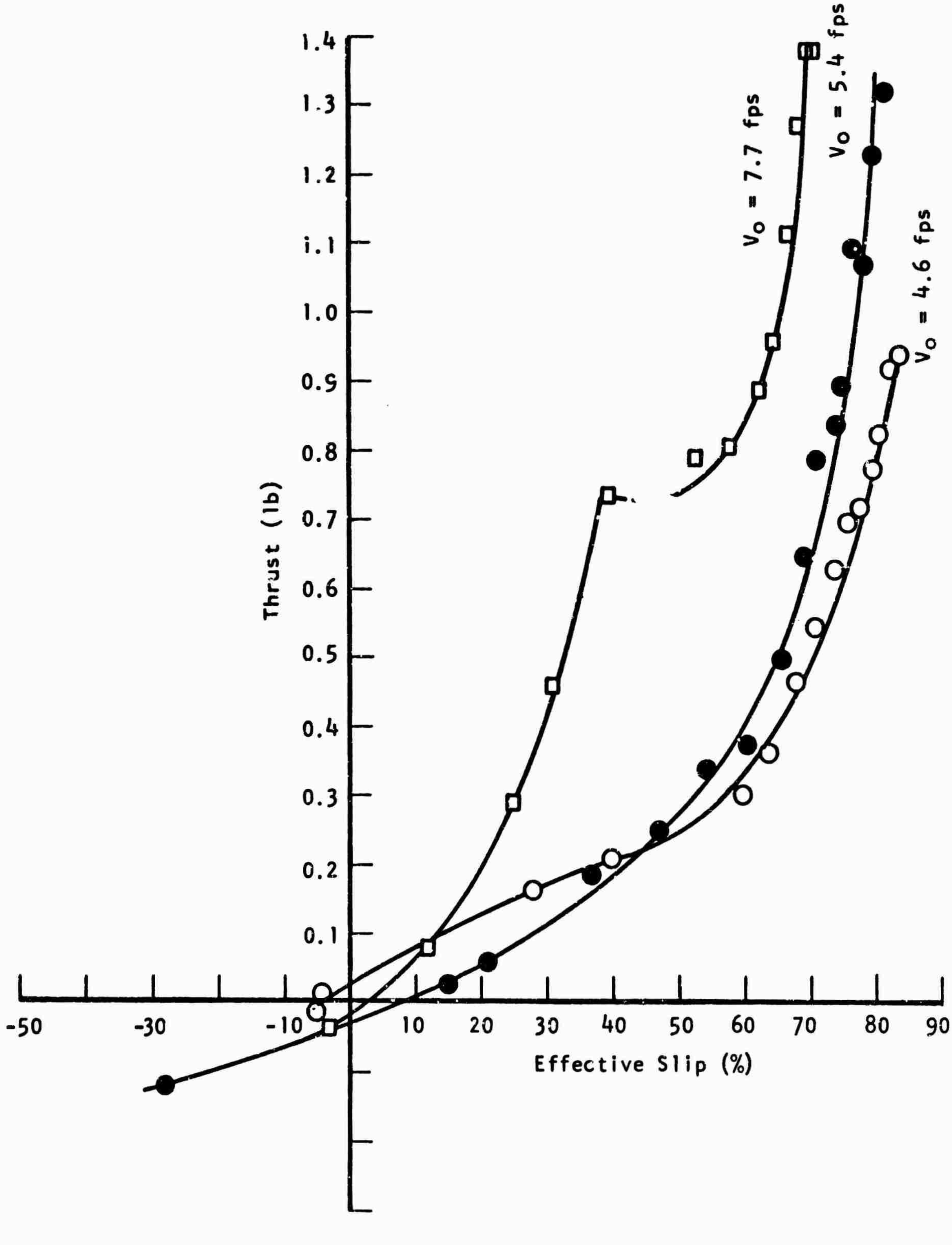


FIGURE 22. THRUST VERSUS EFFECTIVE SLIP FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 6-BLADE WHEEL AND A BLADE IMMERSION DEPTH OF 0.50 INCH

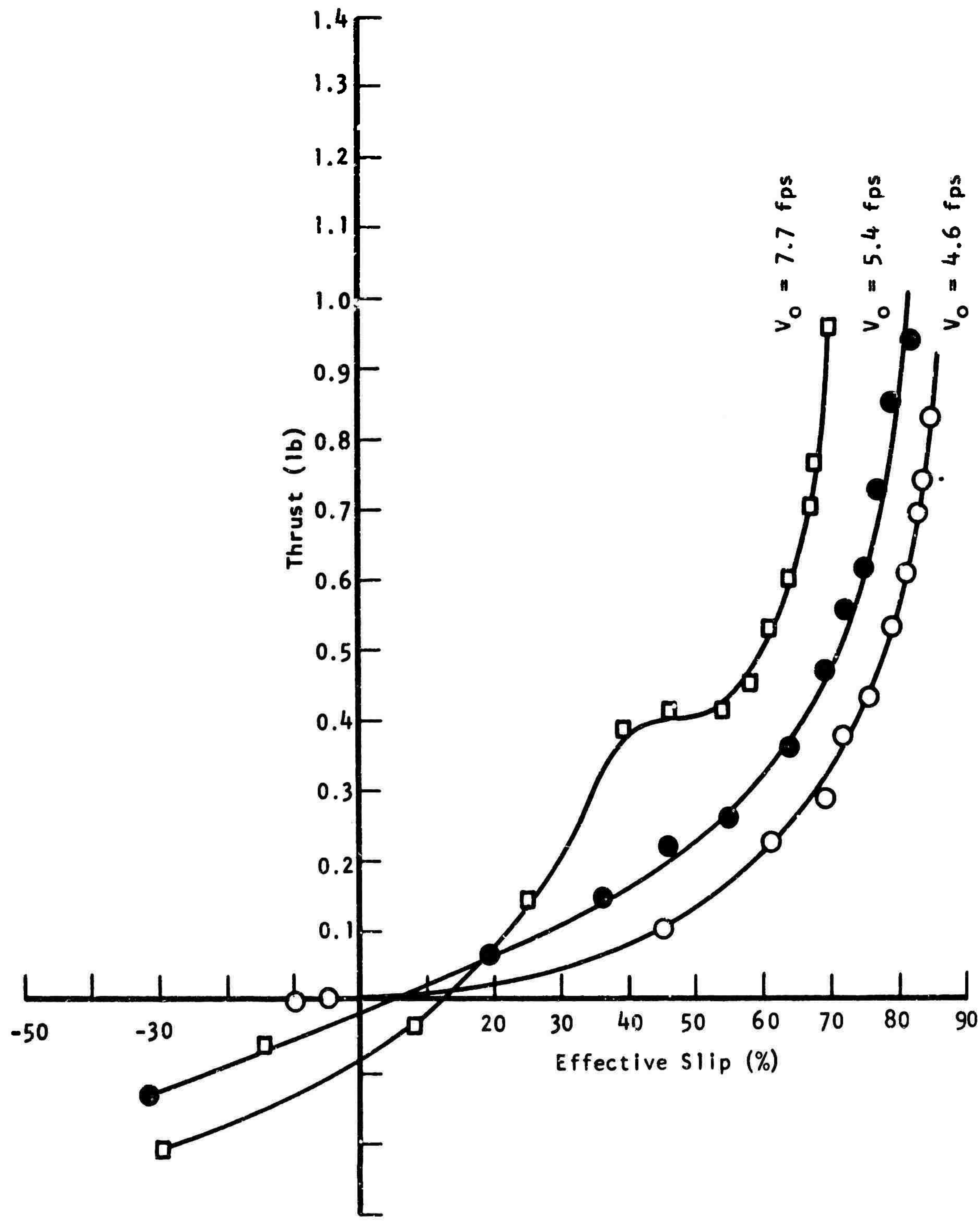


FIGURE 23. THRUST VERSUS EFFECTIVE SLIP FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 12-BLADE WHEEL AND A BLADE IMMERSION DEPTH OF 0.50 INCH

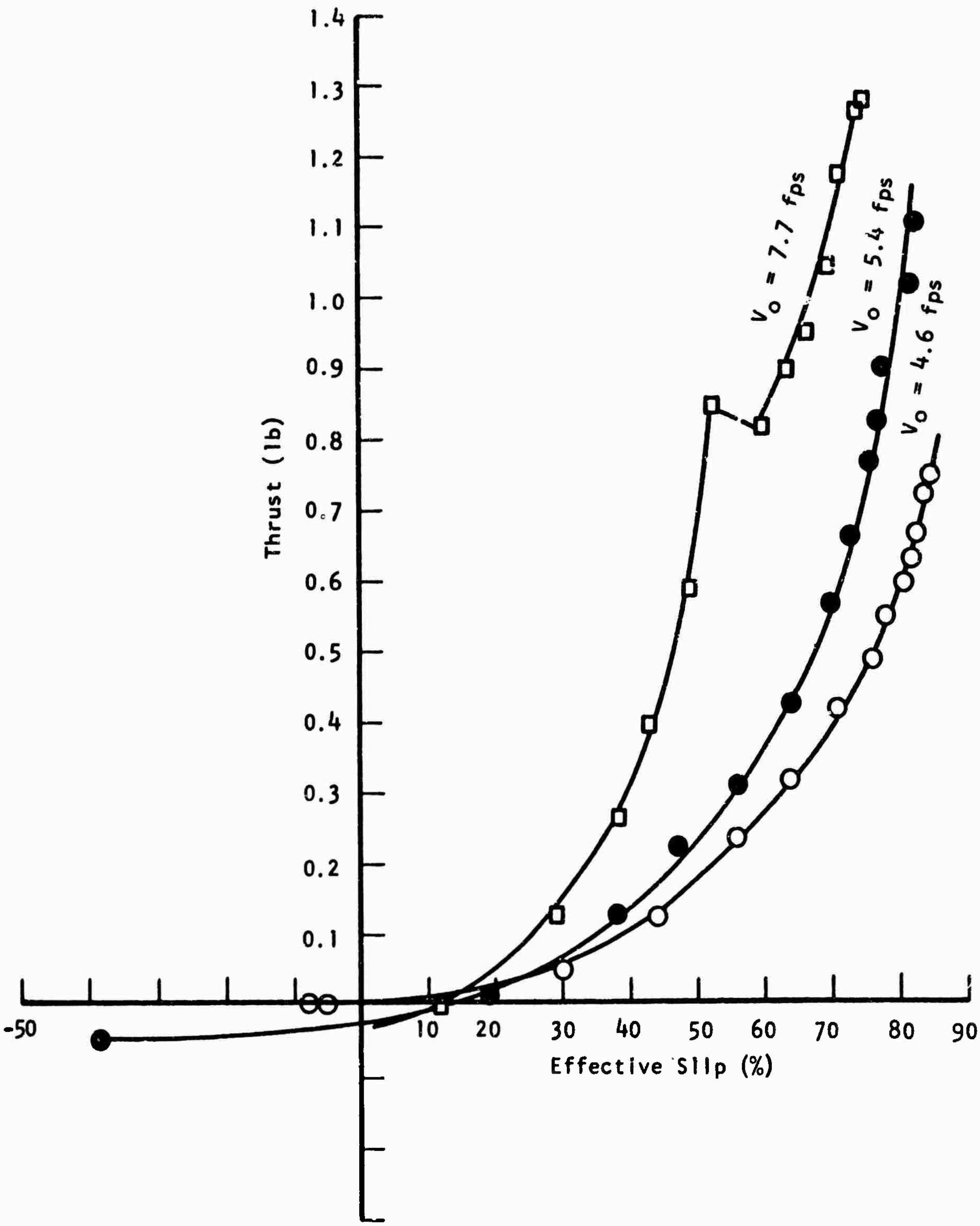


FIGURE 24. THRUST VERSUS EFFECTIVE SLIP FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 6-BLADE WHEEL AND A BLADE IMMERSION DEPTH OF 0.30 INCH

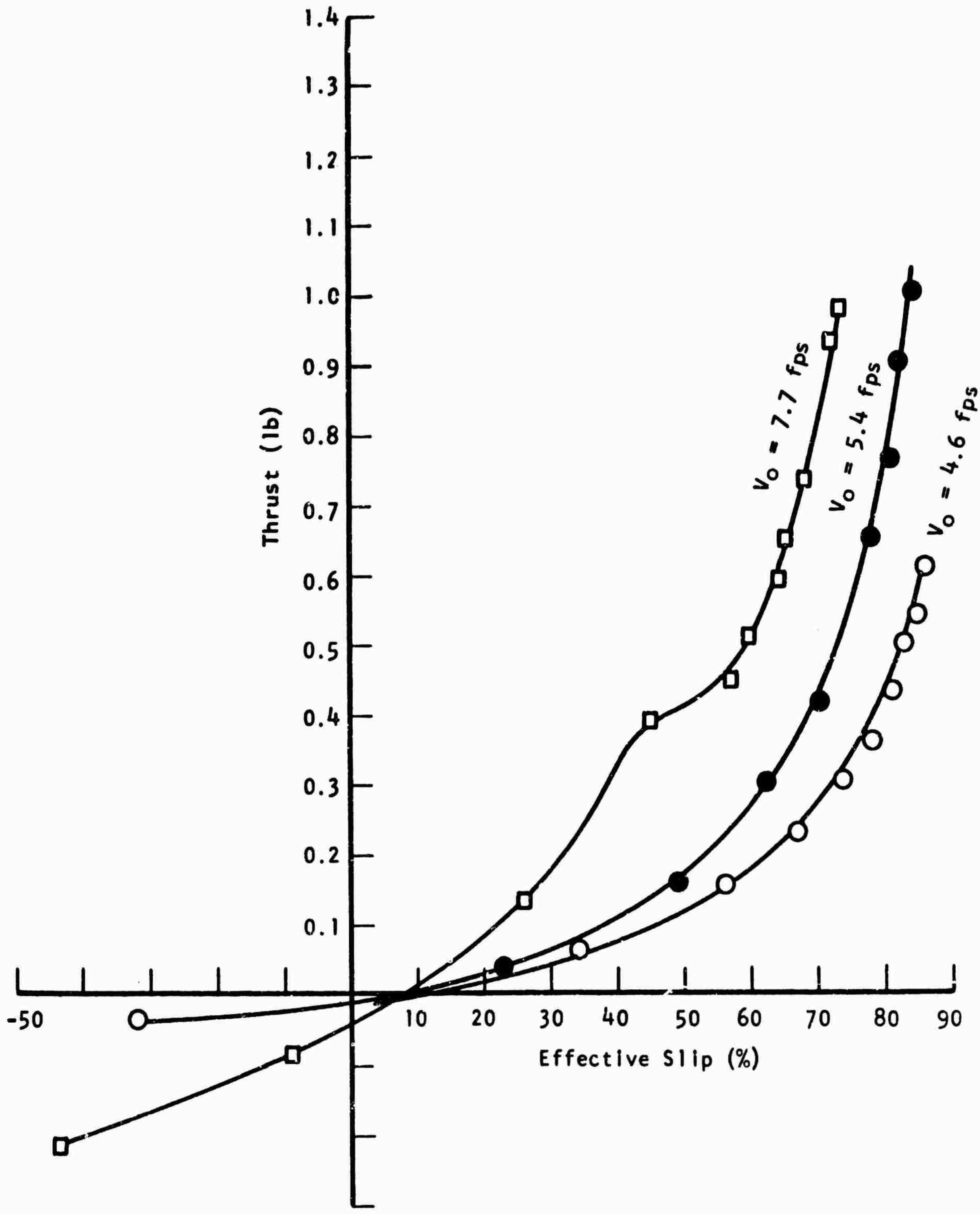


FIGURE 25. THRUST VERSUS EFFECTIVE SLIP FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 12-BLADE WHEEL AND A BLADE IMMERSION DEPTH OF 0.30 INCH

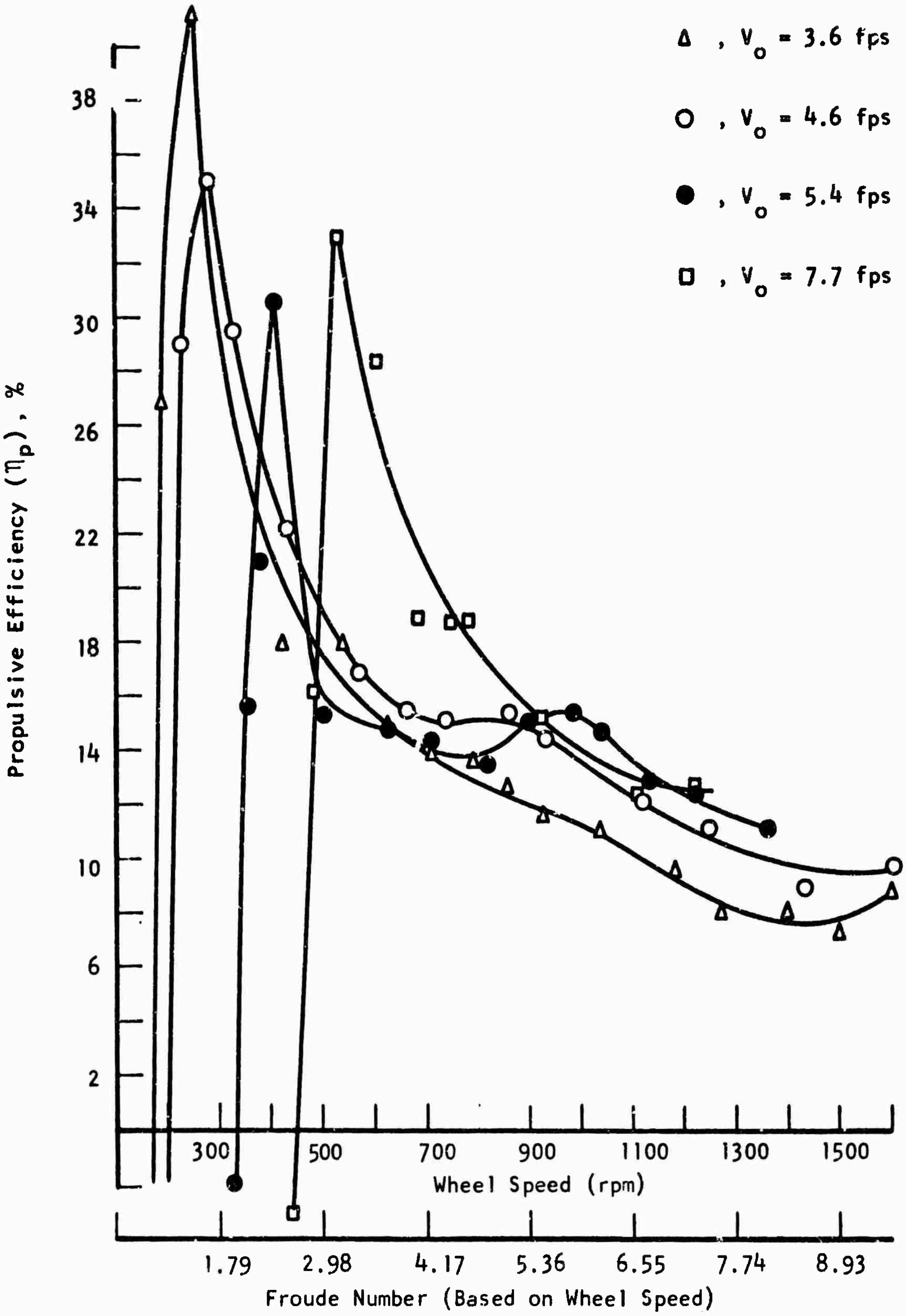


FIGURE 26. PROPULSIVE EFFICIENCY VERSUS WHEEL SPEED AND FROUDE NUMBER FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 6-BLADE WHEEL WITH AN IMMERSION DEPTH OF 0.80 INCH

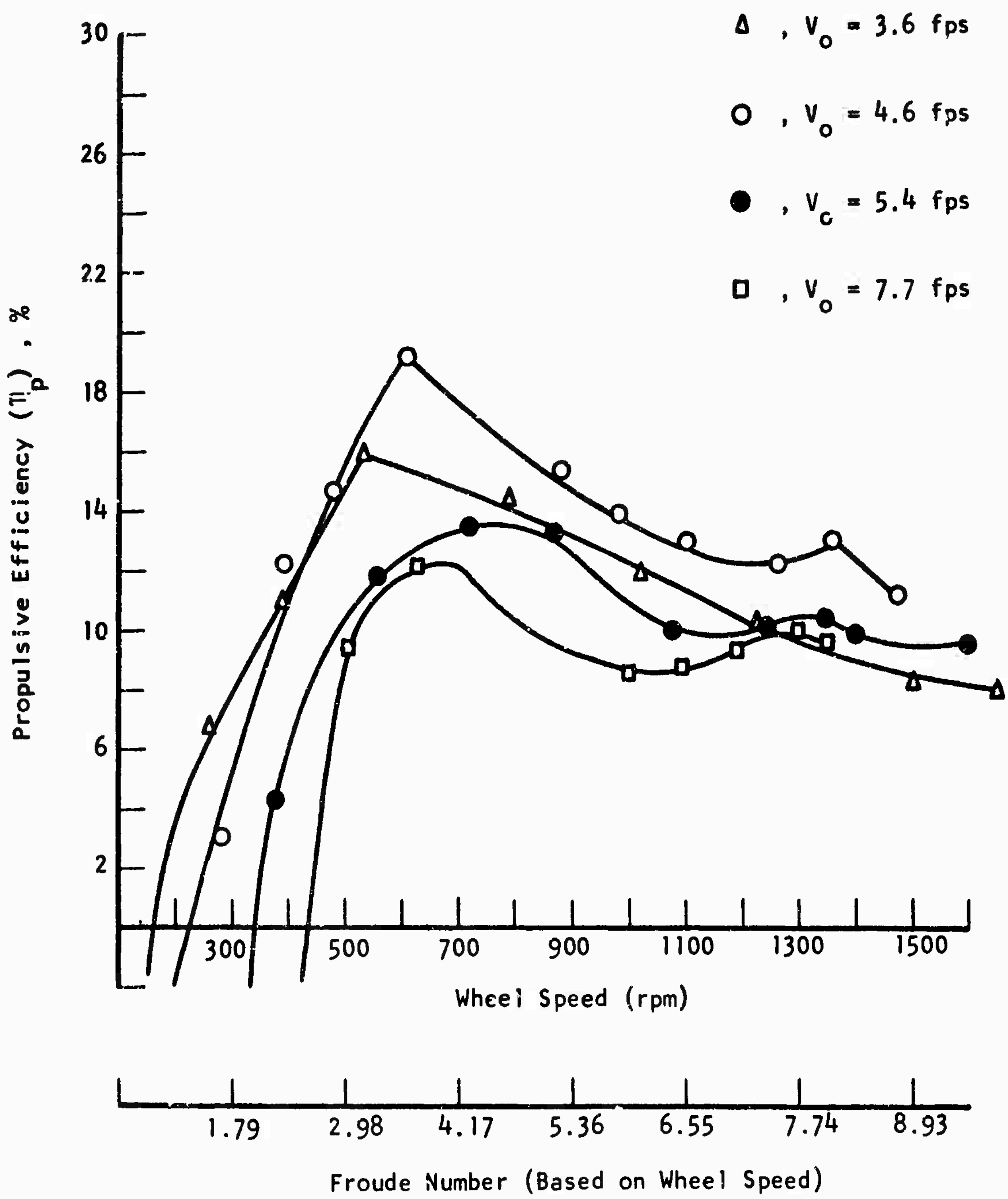


FIGURE 27. PROPULSIVE EFFICIENCY VERSUS WHEEL SPEED AND FROUDE NUMBER FOR VARIOUS ADVANCE VELOCITIES (V_O), FOR A 12-BLADE WHEEL WITH AN IMMERSION DEPTH OF 0.80 INCH

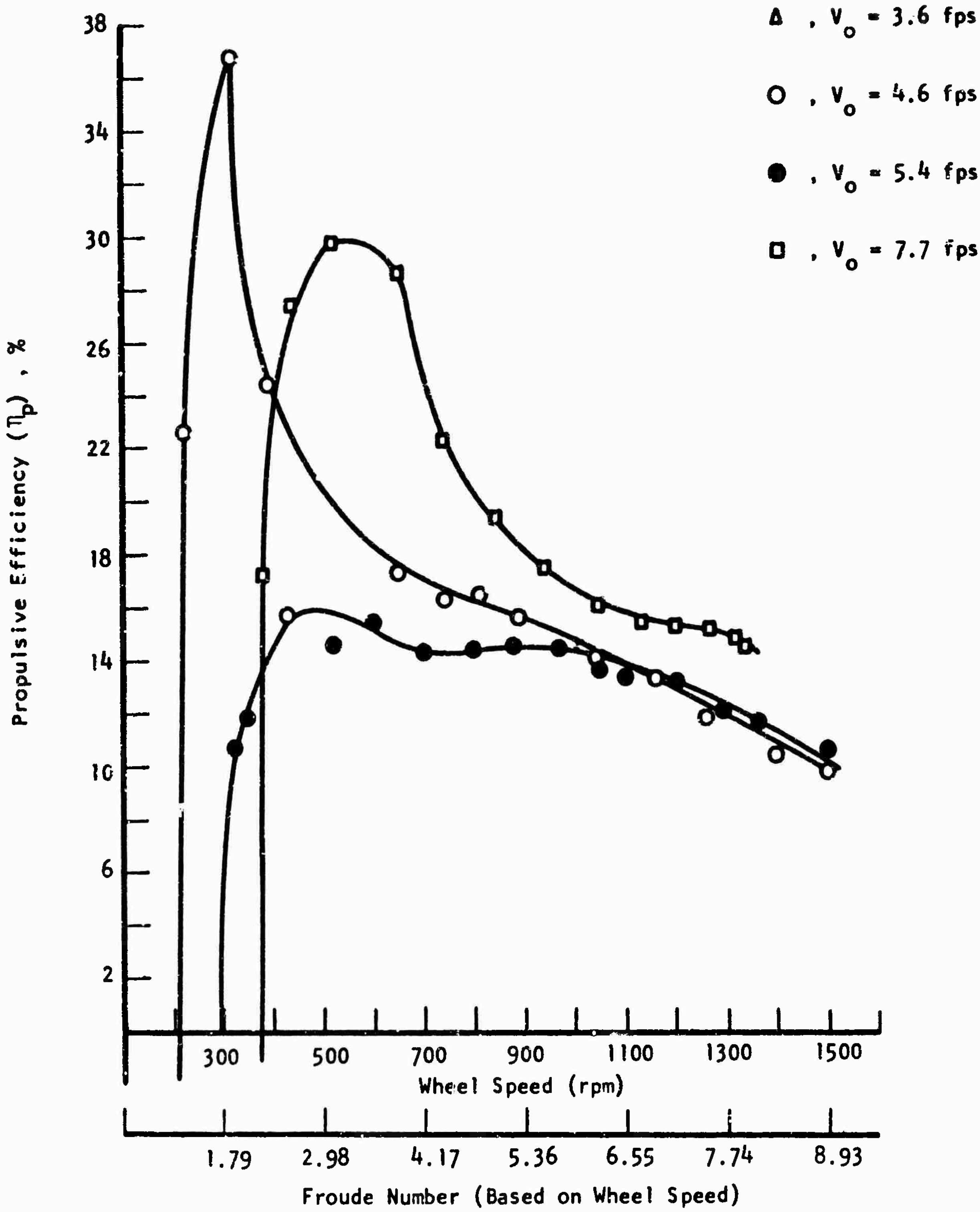


FIGURE 28. PROPULSIVE EFFICIENCY VERSUS WHEEL SPEED AND FROUDE NUMBER FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 6-BLADE WHEEL WITH AN IMMERSION DEPTH OF 0.50 INCH

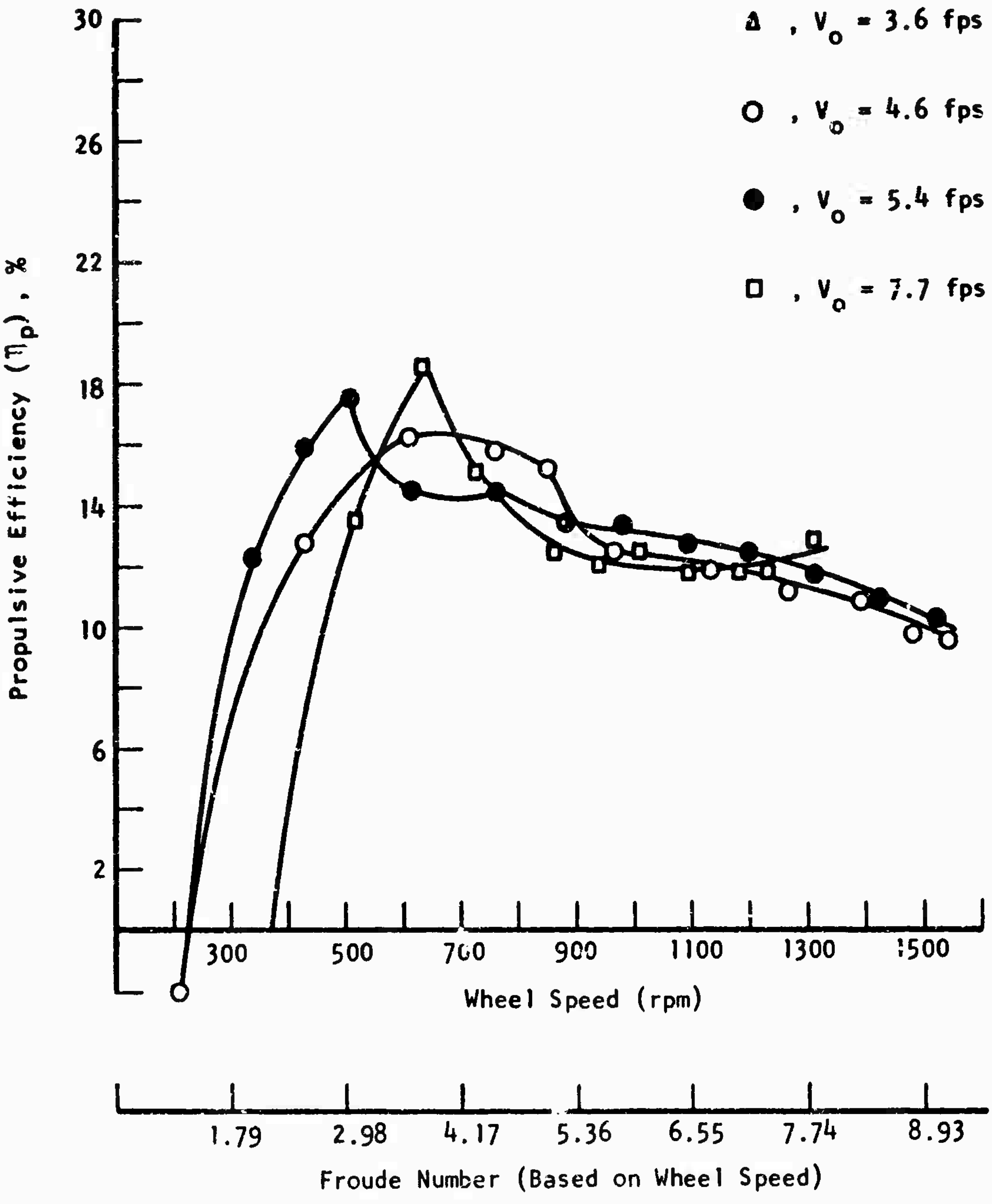
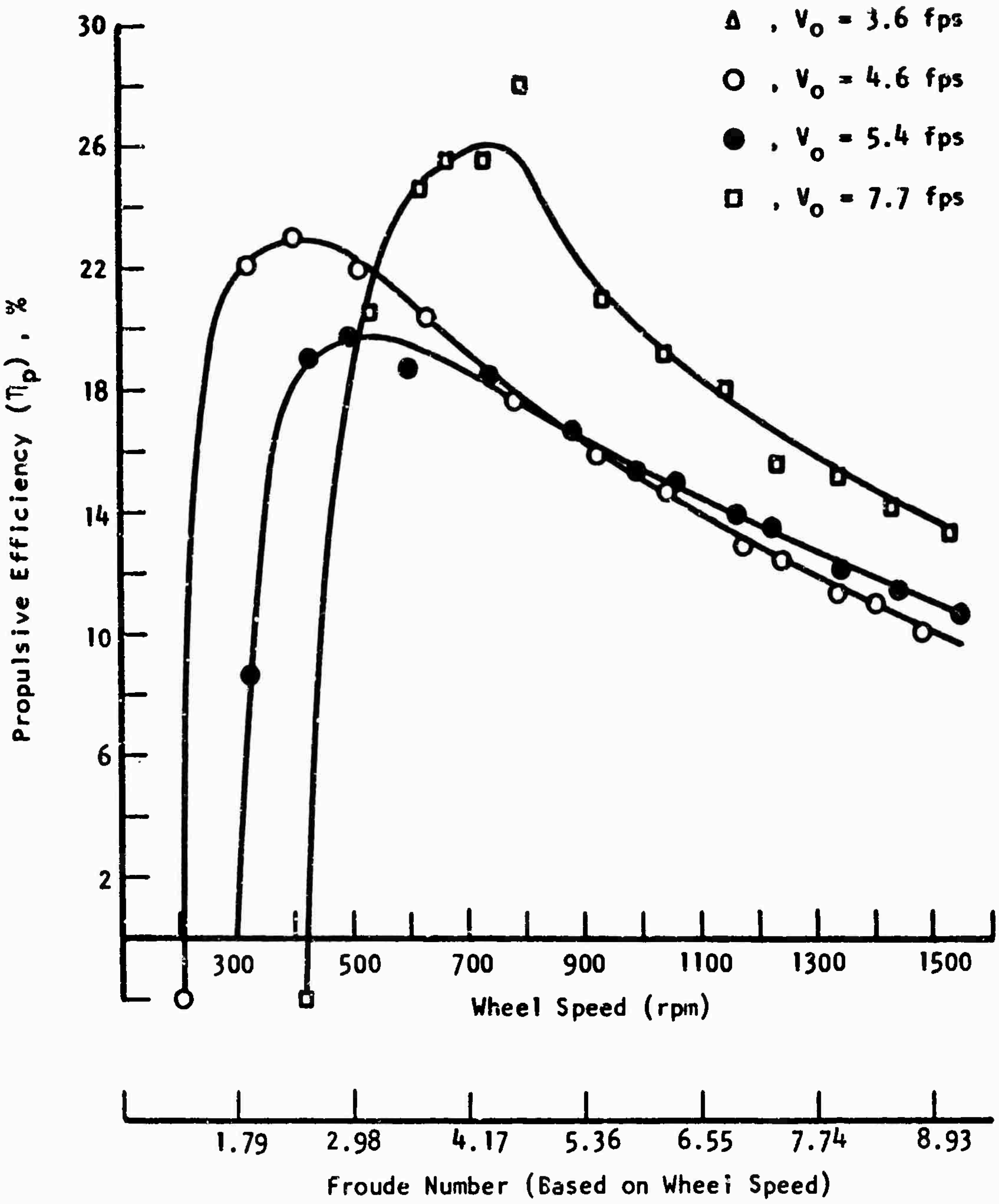


FIGURE 29. PROPULSIVE EFFICIENCY VERSUS WHEEL SPEED AND FROUDE NUMBER FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 12-BLADE WHEEL WITH AN IMMERSION DEPTH OF 0.50 INCH



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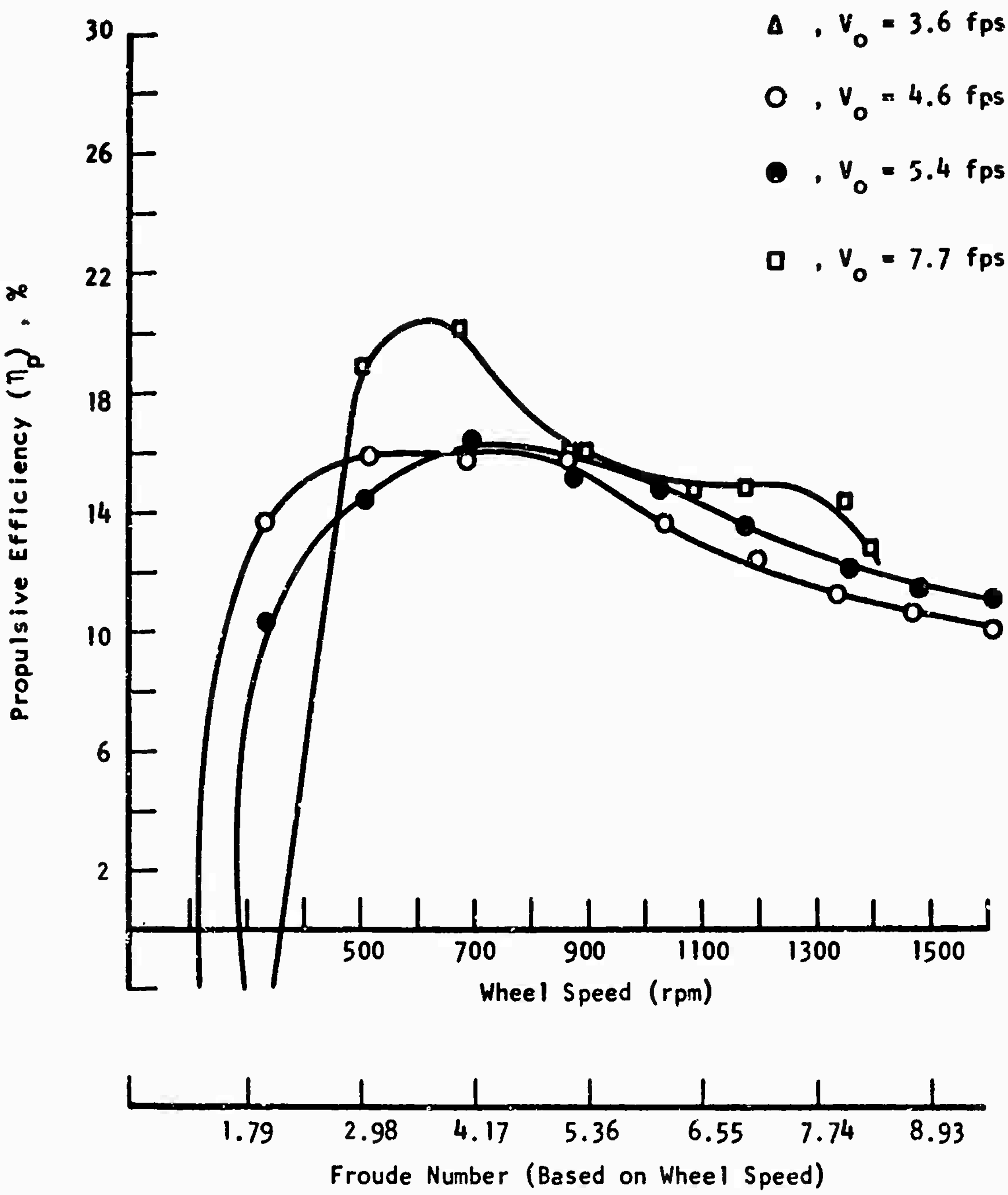


FIGURE 31. PROPULSIVE EFFICIENCY VERSUS WHEEL SPEED AND FROUDE NUMBER FOR VARIOUS ADVANCE VELOCITIES (V_O), FOR A 12-BLADE WHEEL WITH AN IMMERSION DEPTH OF 0.30 INCH

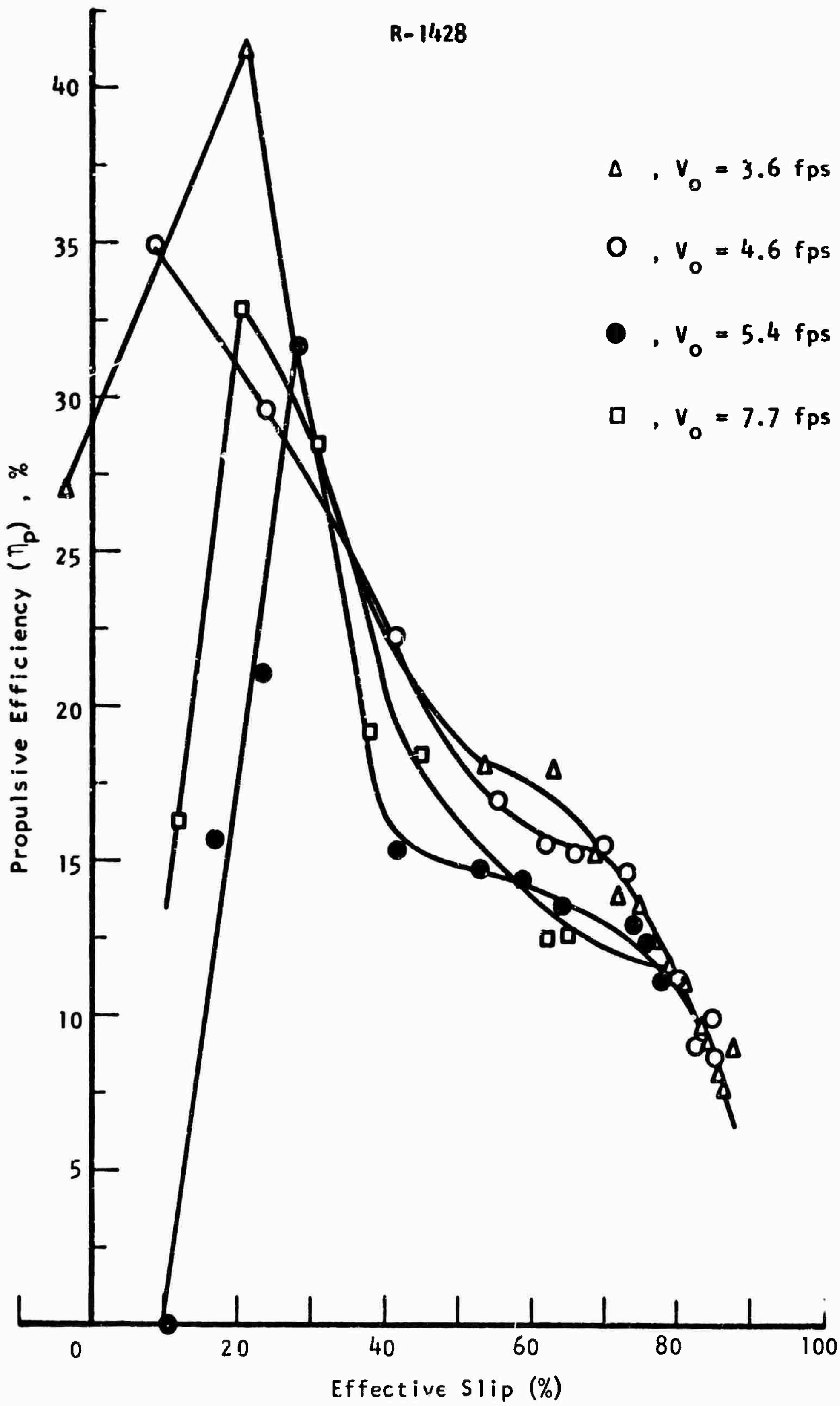


FIGURE 32. PROPULSIVE EFFICIENCY VERSUS EFFECTIVE SLIP FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 6-BLADE WHEEL WITH A BLADE IMMERSION DEPTH OF 0.80 INCH

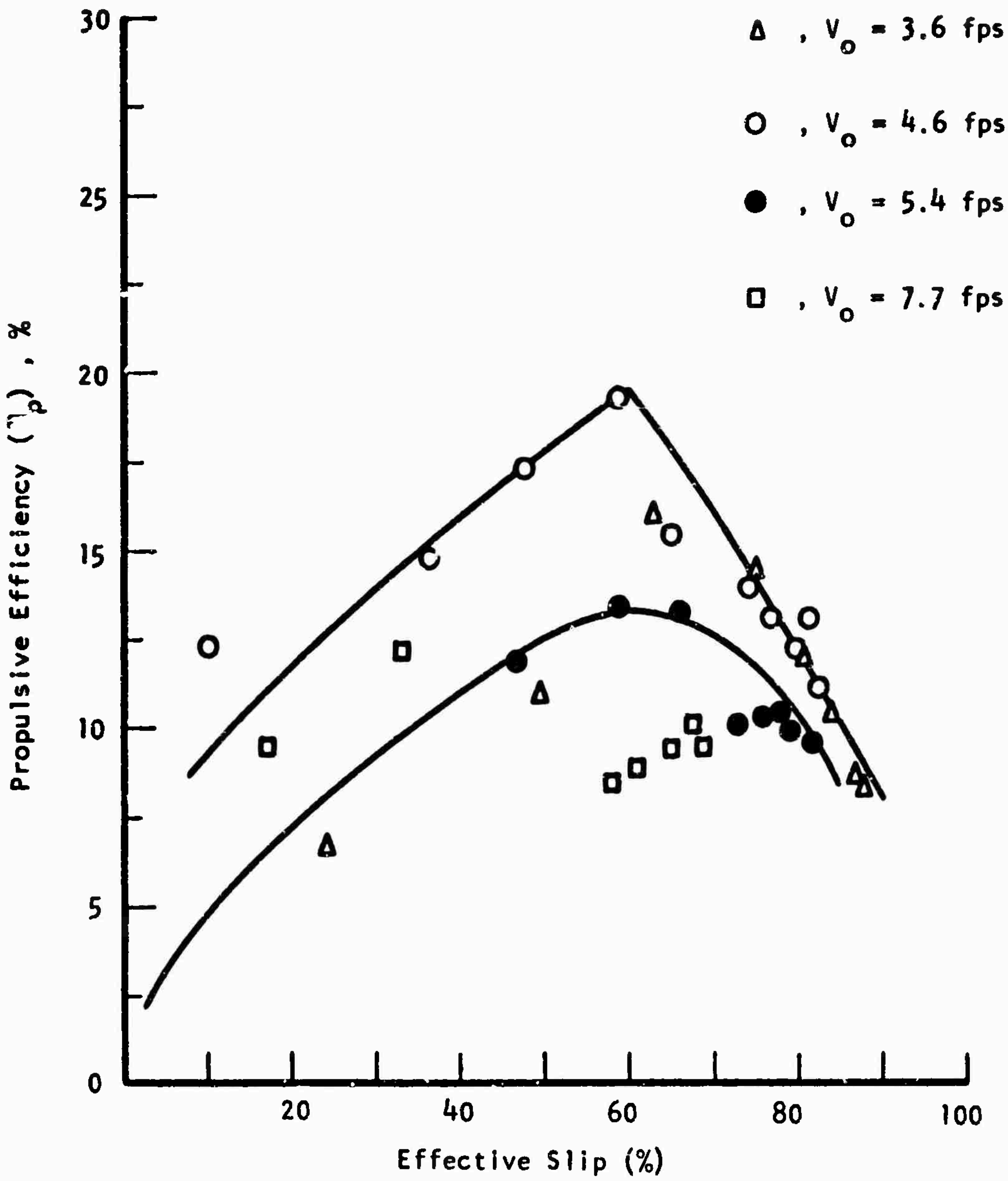


FIGURE 33. PROPULSIVE EFFICIENCY VERSUS EFFECTIVE SLIP FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 12-BLADE WHEEL WITH A BLADE IMMERSION DEPTH OF 0.80 INCH

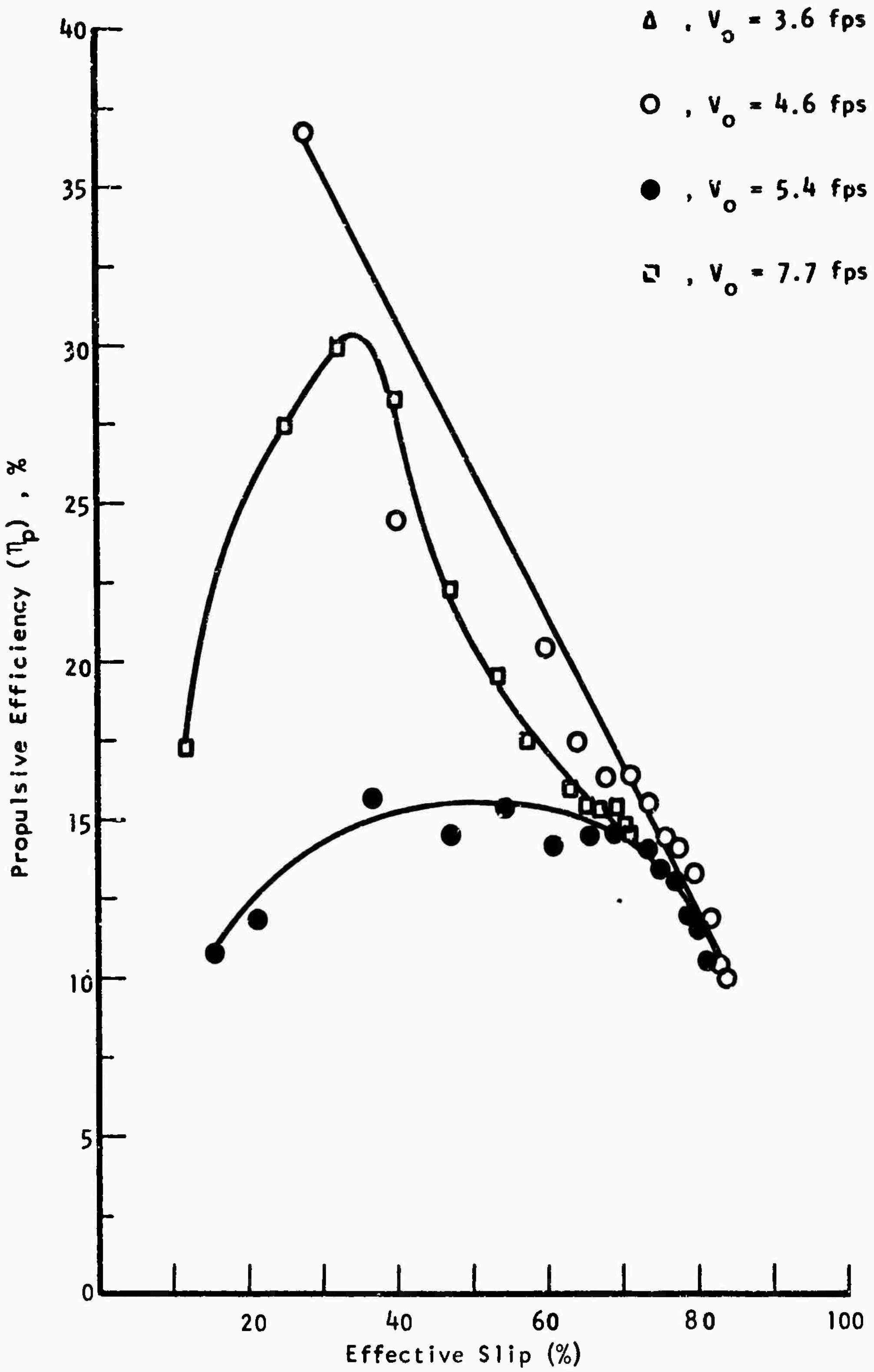
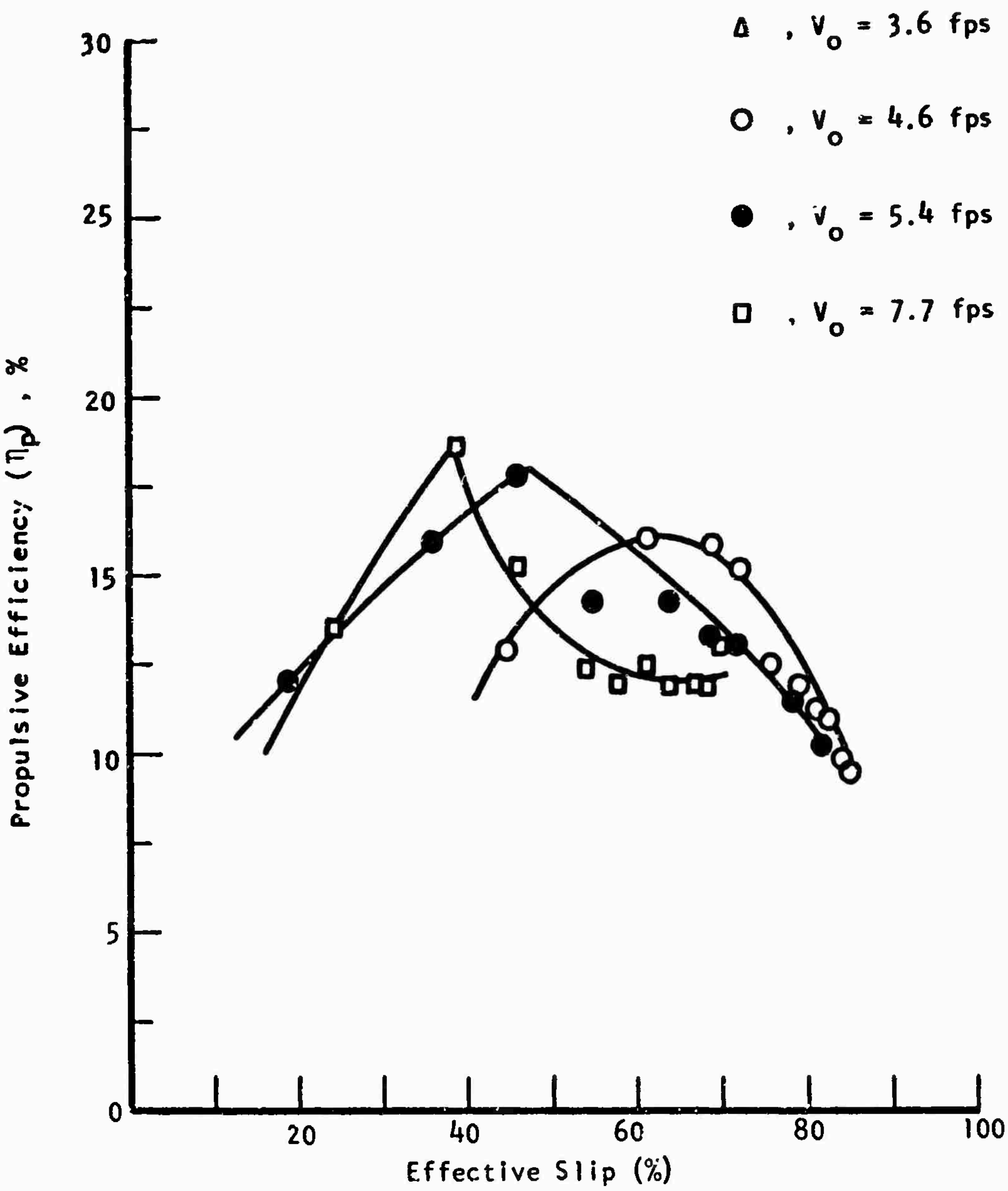


FIGURE 34. PROPULSIVE EFFICIENCY VERSUS EFFECTIVE SLIP FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 6-BLADE WHEEL WITH A BLADE IMMERSION DEPTH OF 0.50 INCH



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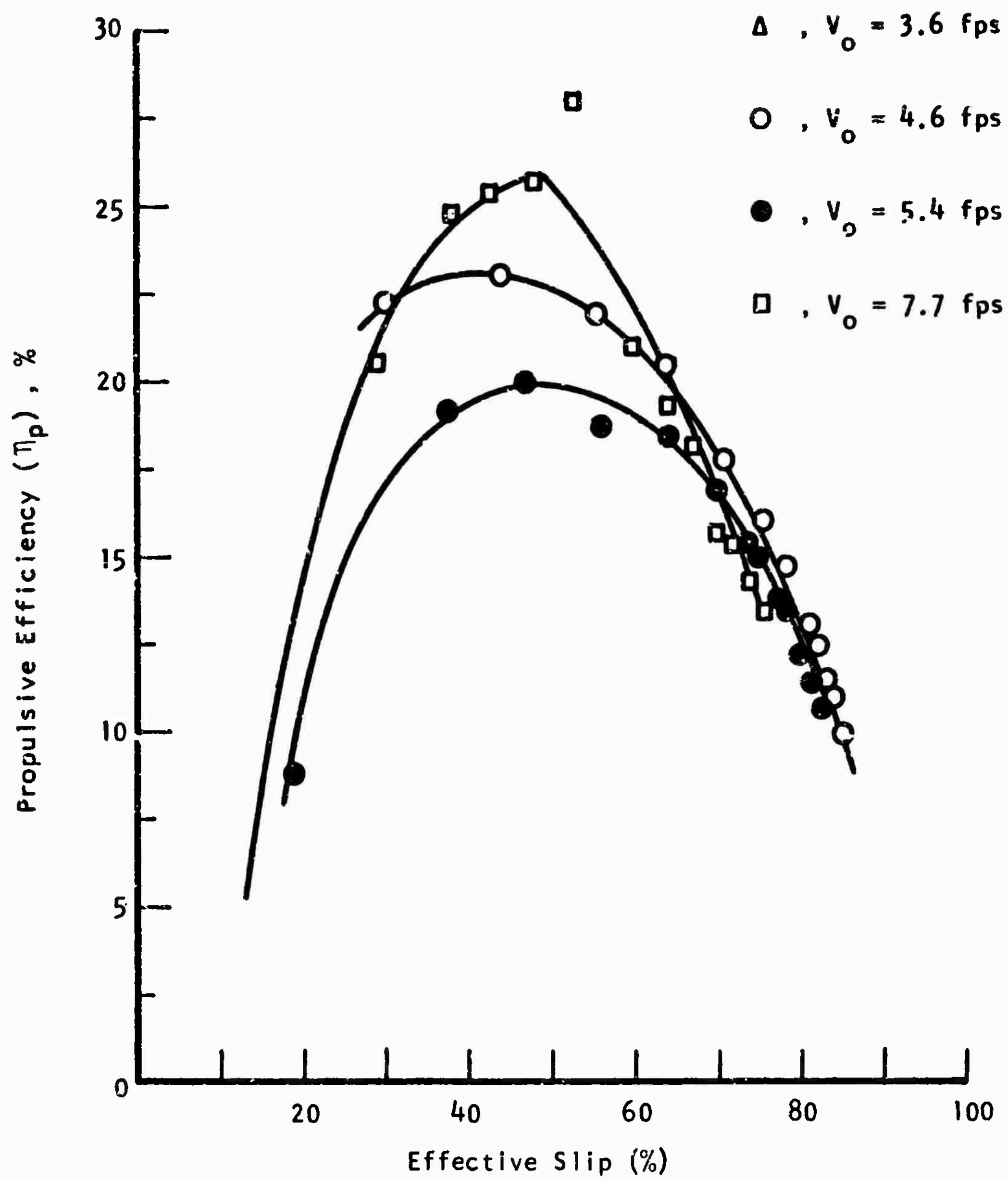

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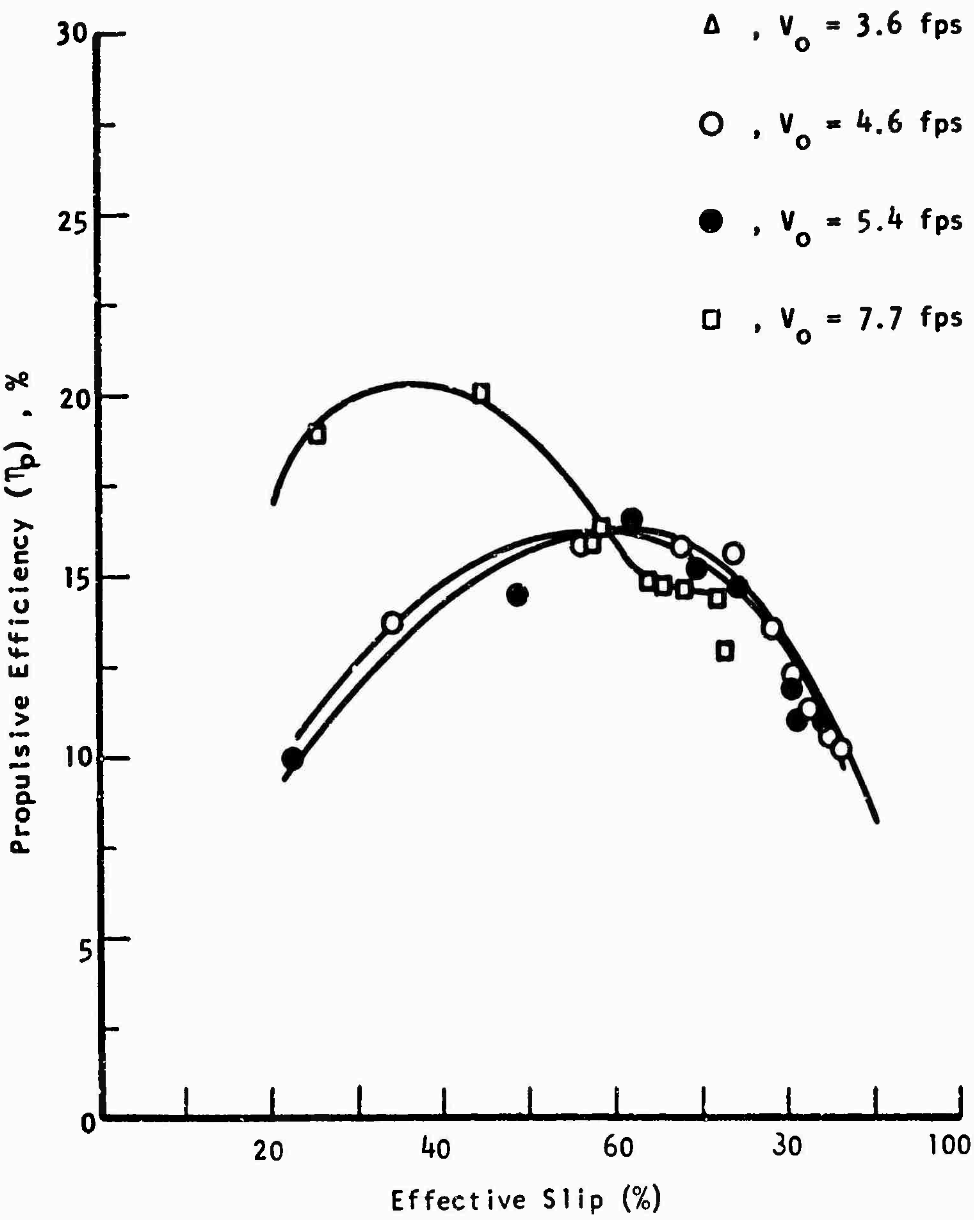

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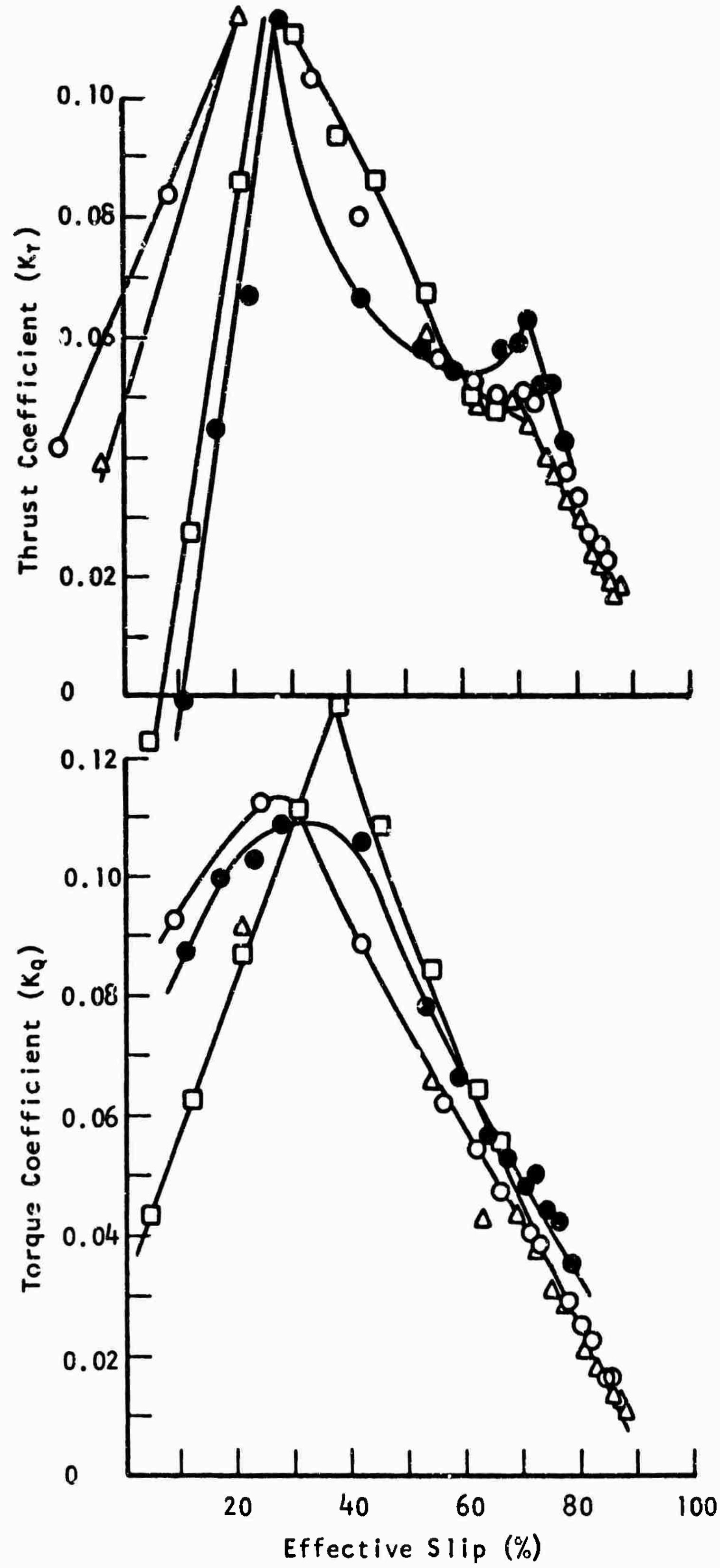


FIGURE 38. WHEEL THRUST AND TORQUE COEFFICIENTS (K_T, K_Q) VERSUS EFFECTIVE SLIP FOR VARIOUS ADVANCE VELOCITIES (V_O), FOR A 6-BLADE WHEEL WITH AN IMMERSION DEPTH OF 0.80 INCH

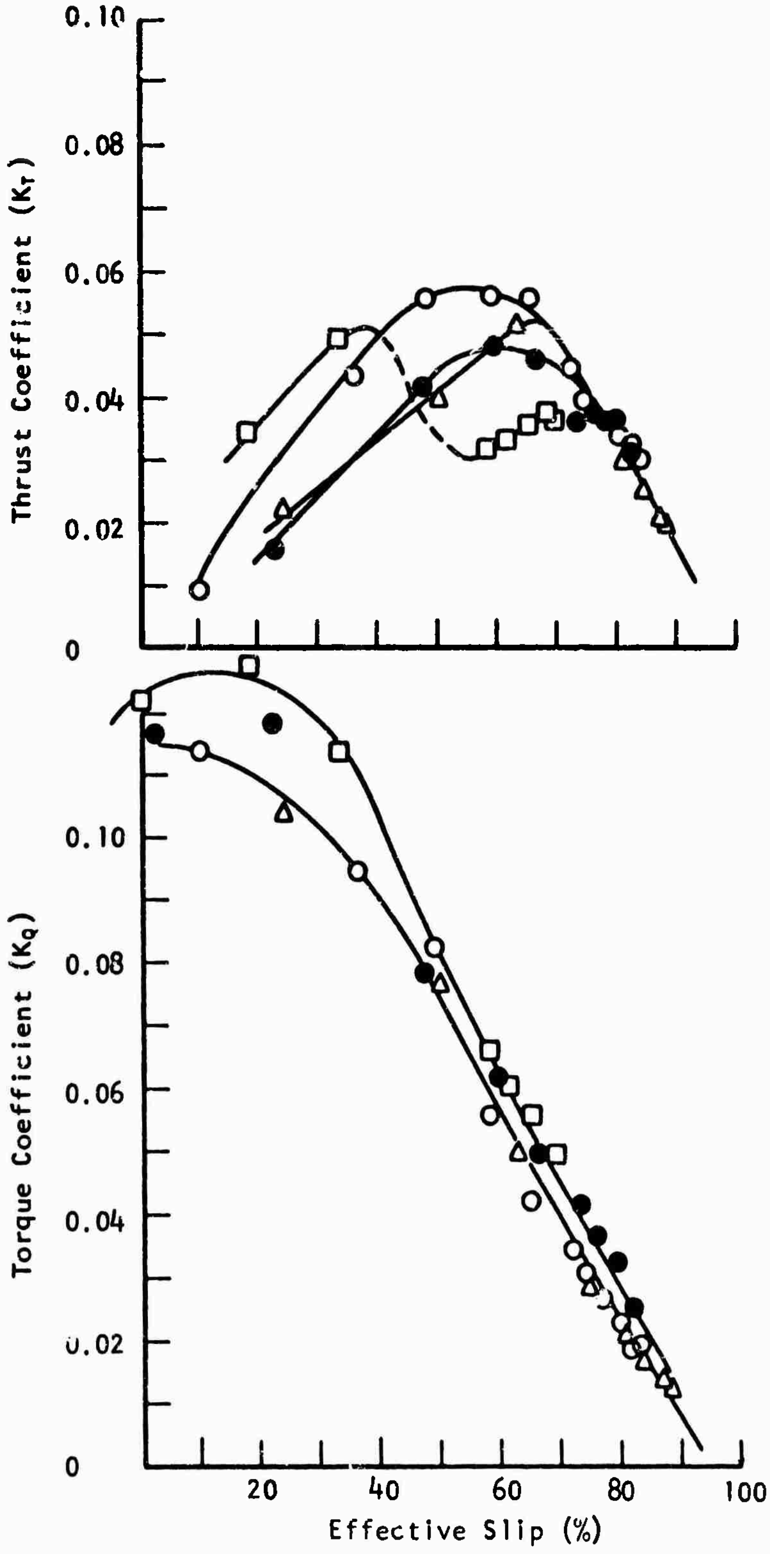


FIGURE 39. WHEEL THRUST AND TORQUE COEFFICIENTS (K_T, K_Q) VERSUS EFFECTIVE SLIP FOR VARIOUS ADVANCE VELOCITIES (V_O), FOR A 12-BLADE WHEEL WITH AN IMMERSION DEPTH OF 0.80 INCH

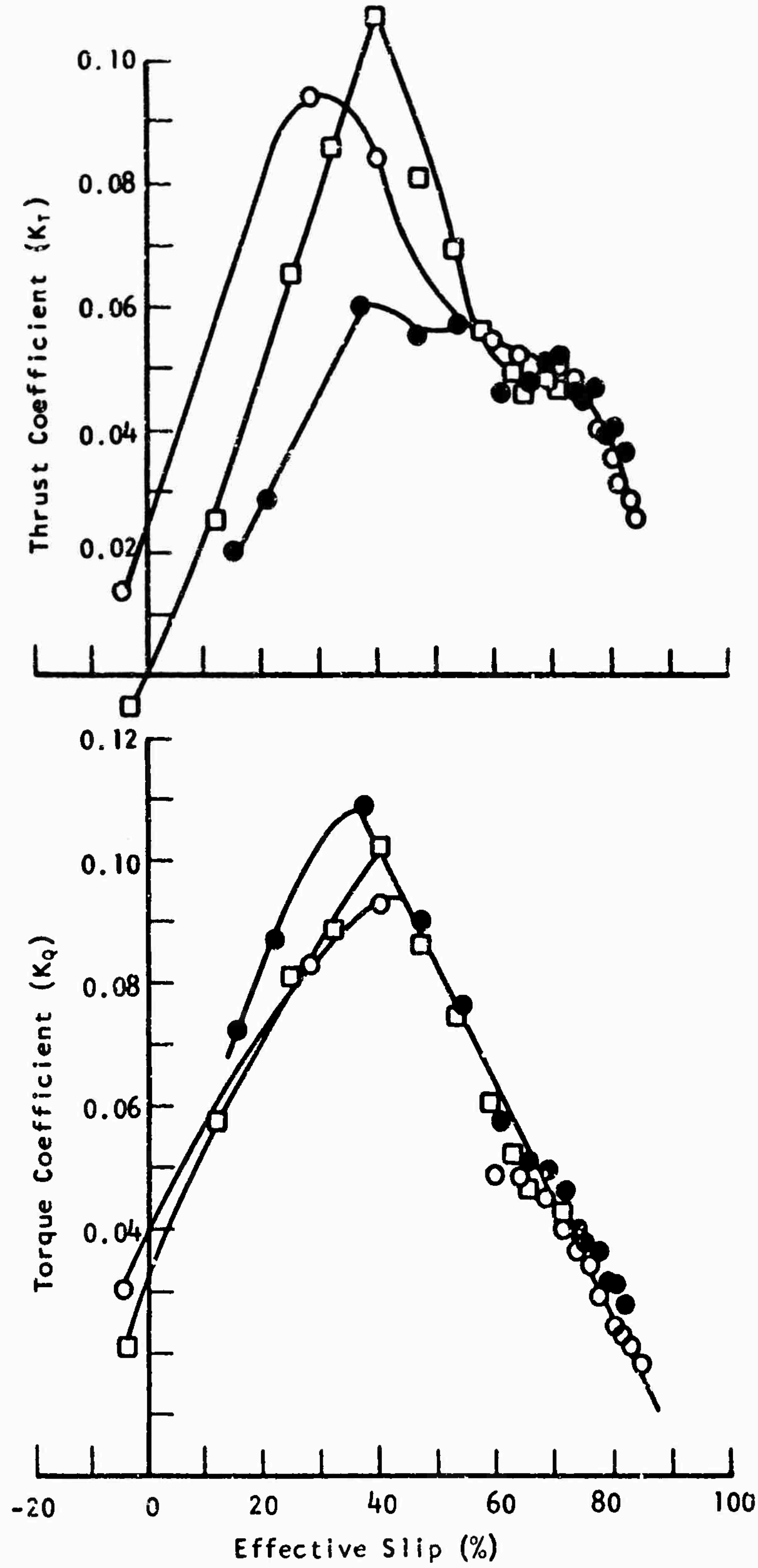


FIGURE 40. WHEEL THRUST AND TORQUE COEFFICIENTS (K_T, K_Q) VERSUS EFFECTIVE SLIP FOR VARIOUS ADVANCE VELOCITIES (V_O), FOR A 6-BLADE WHEEL WITH AN IMMERSION DEPTH OF 0.50 INCH

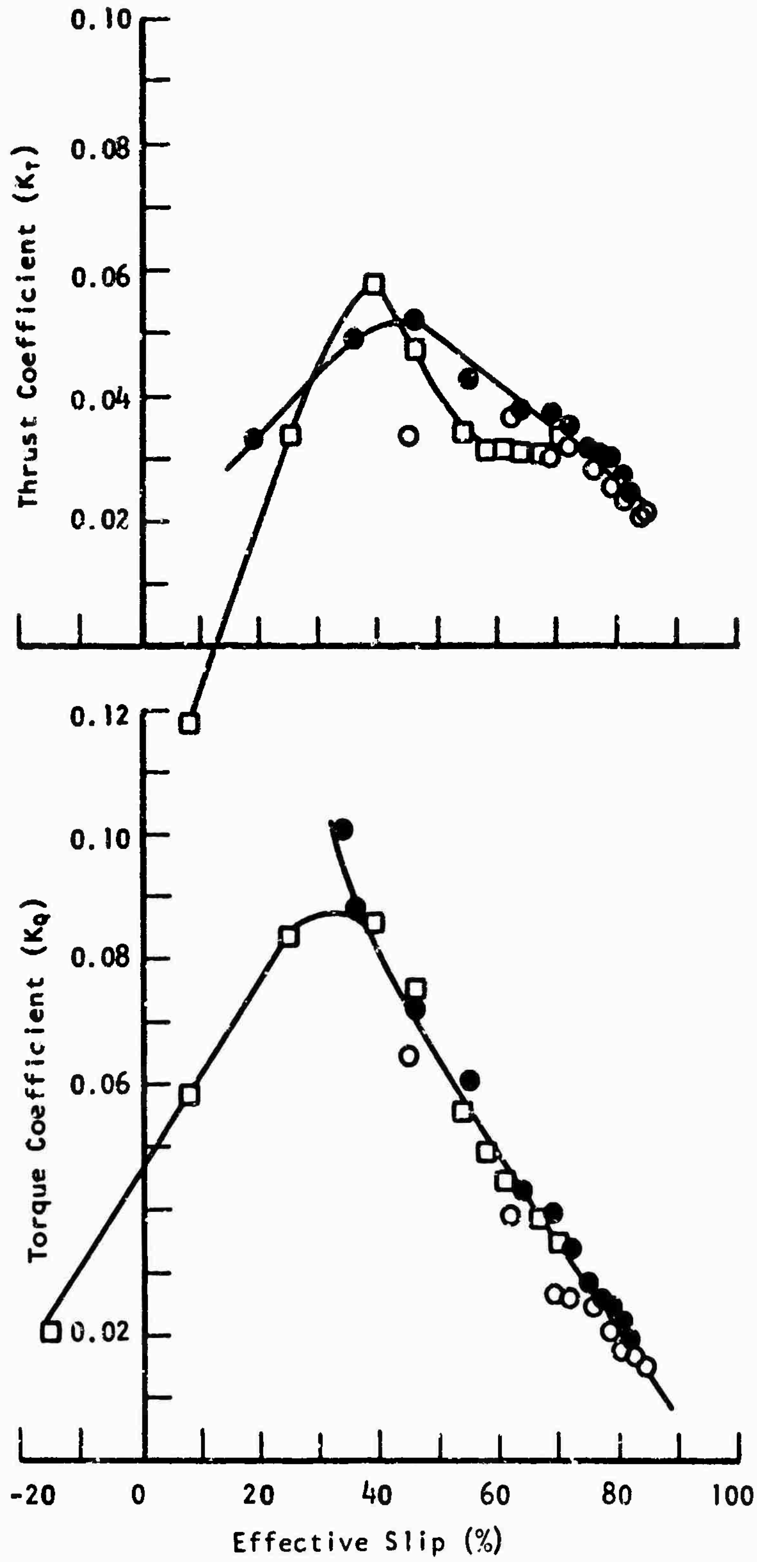
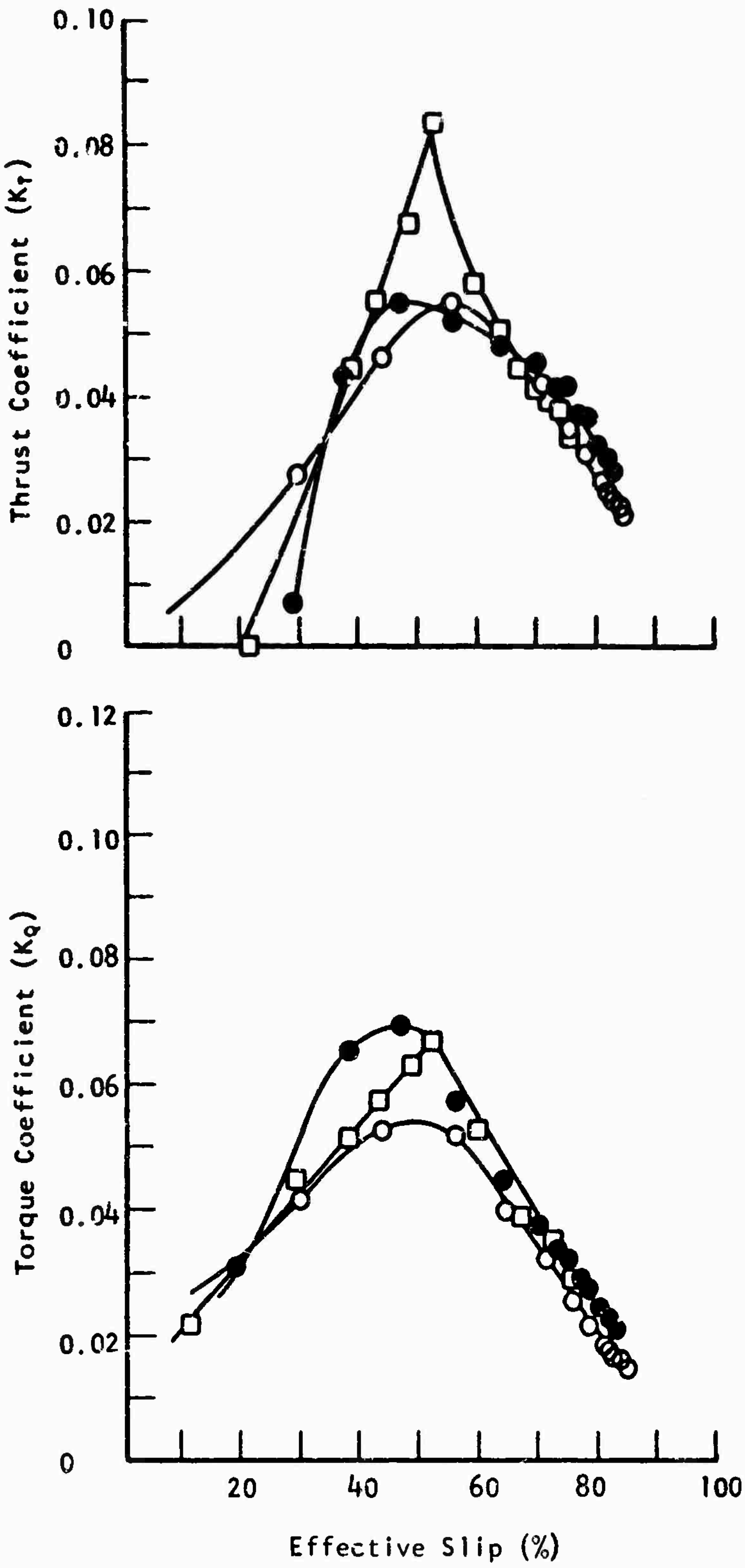


FIGURE 41. WHEEL THRUST AND TORQUE COEFFICIENTS (K_T, K_Q) VERSUS EFFECTIVE SLIP FOR VARIOUS ADVANCE VELOCITIES (V_O), FOR A 12-BLADE WHEEL WITH AN IMMERSION DEPTH OF 0.50 INCH



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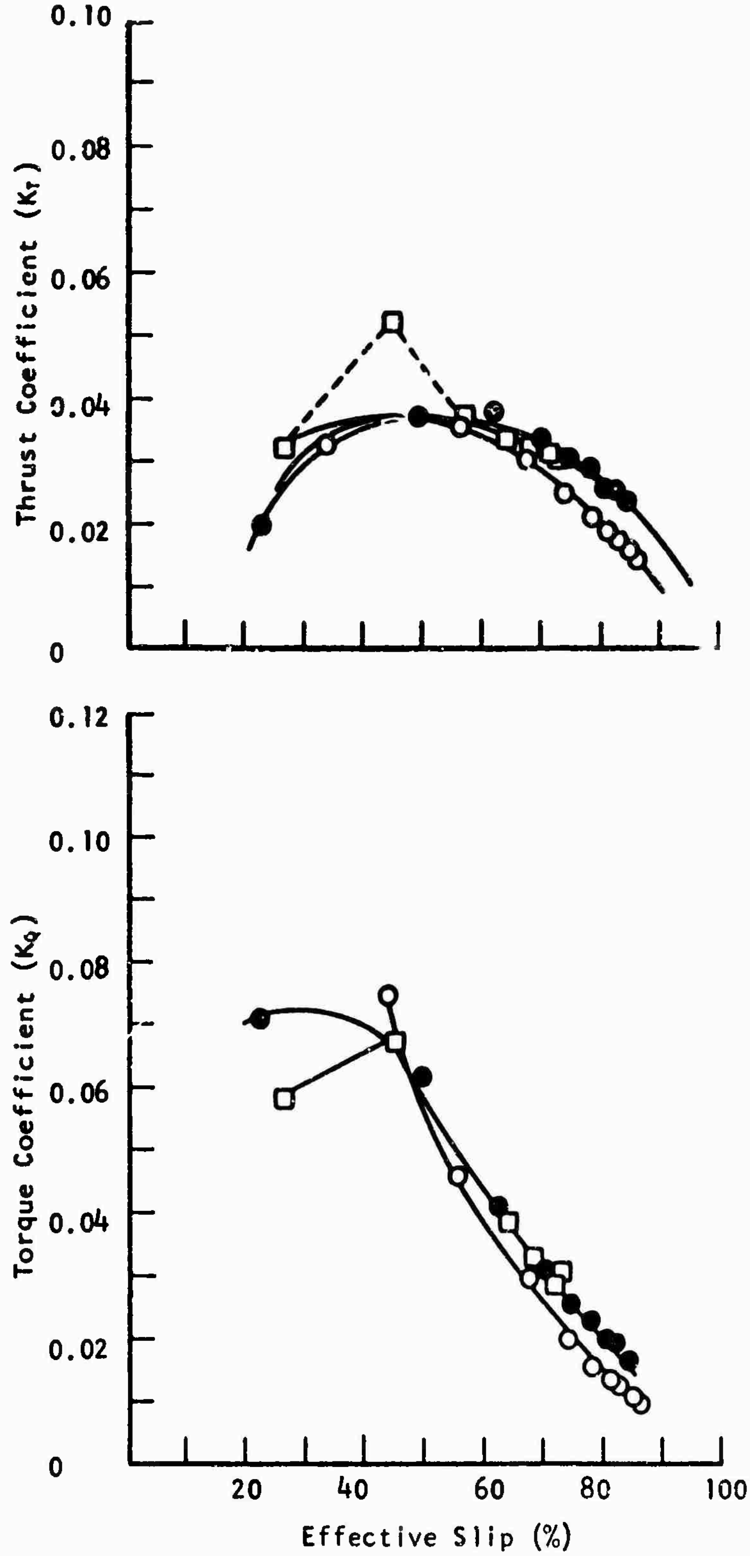

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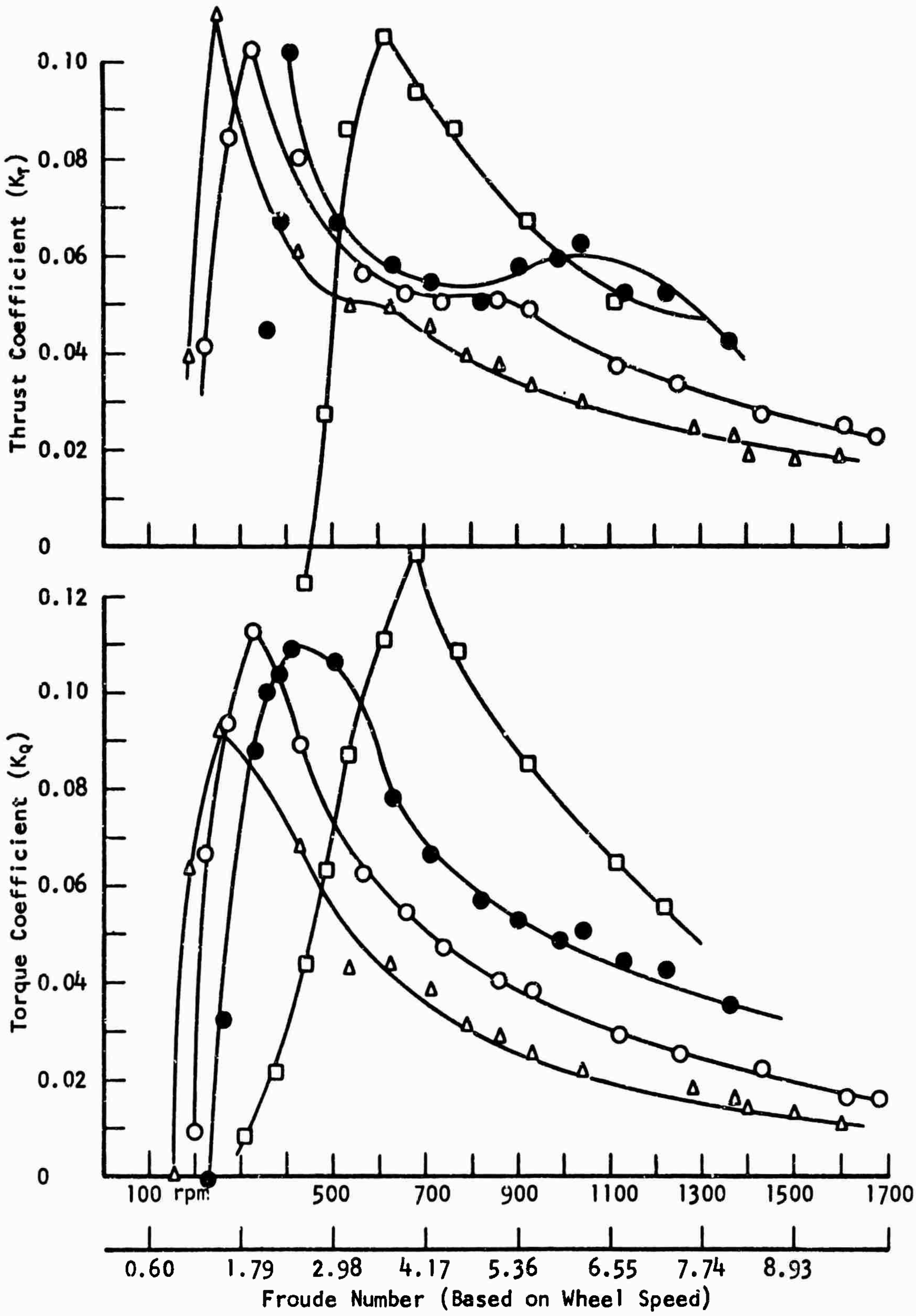

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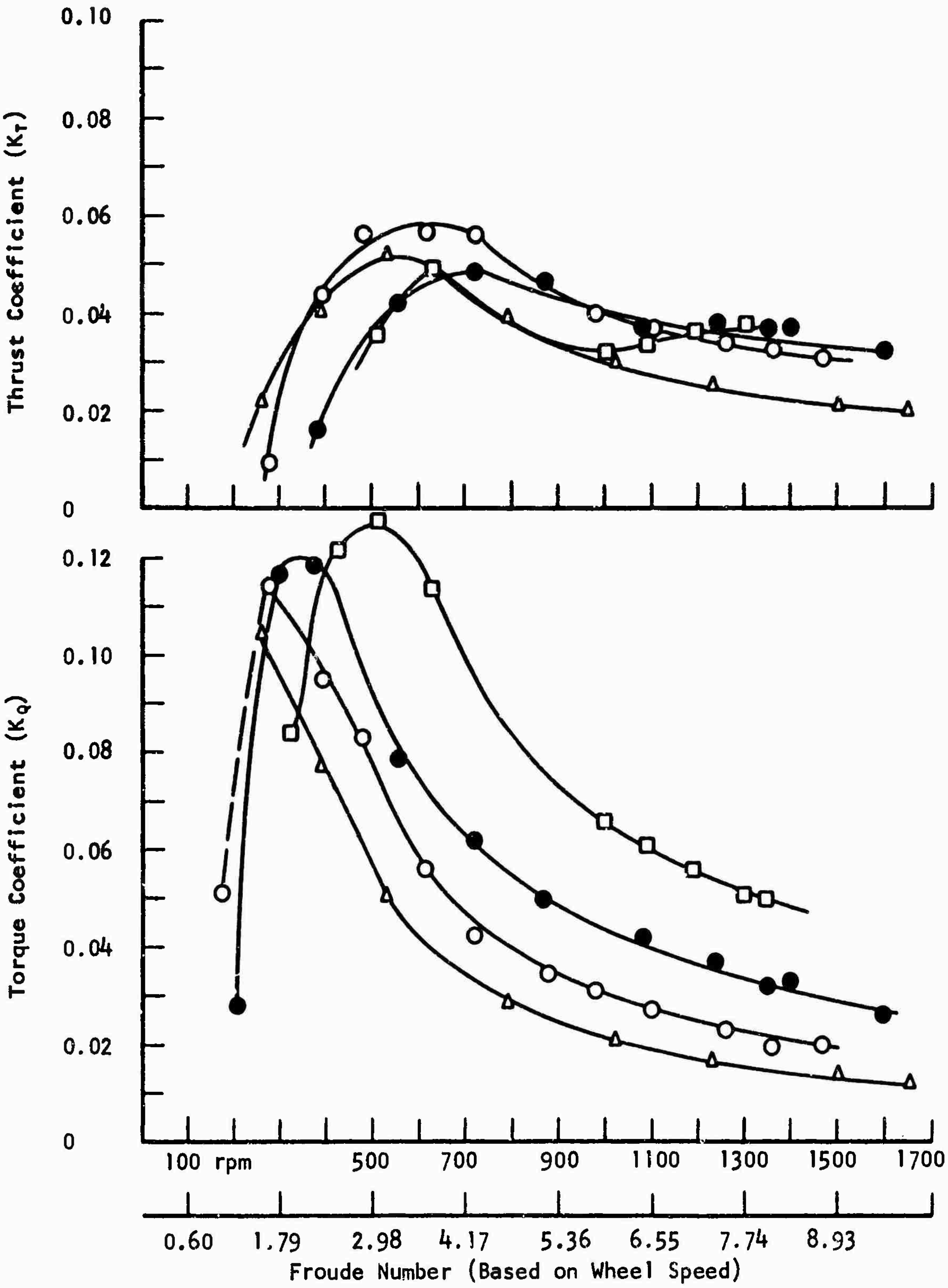

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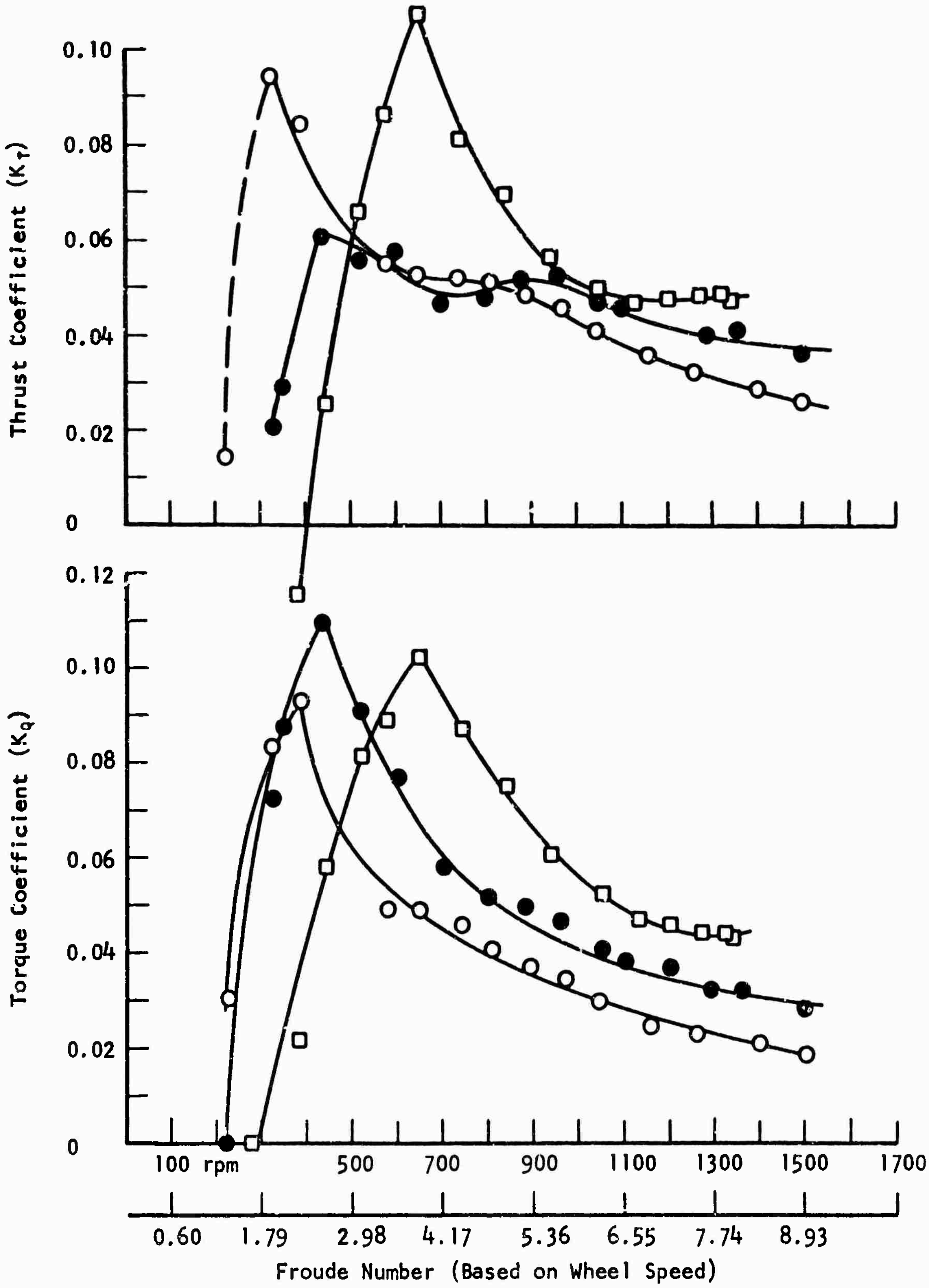

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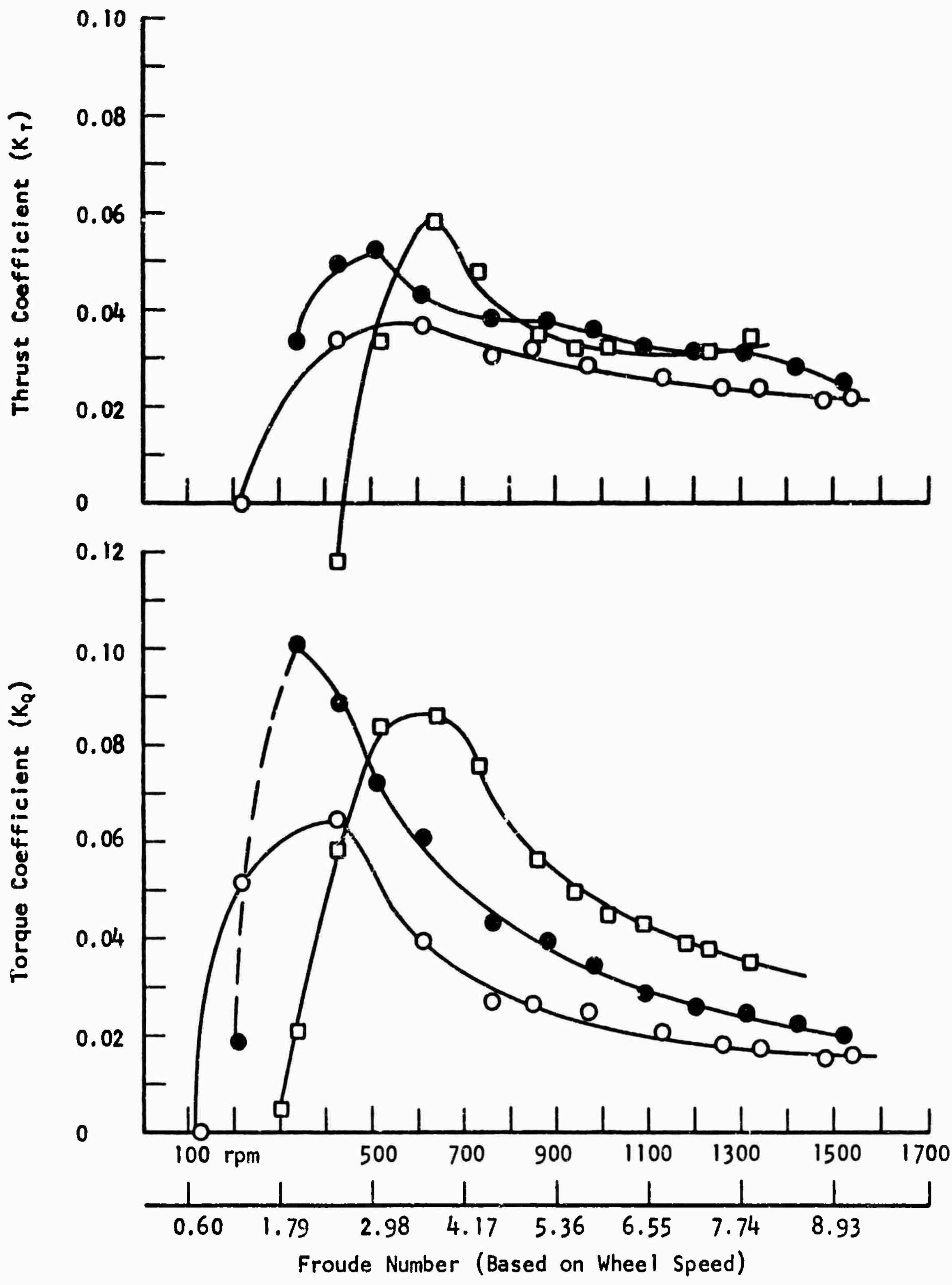

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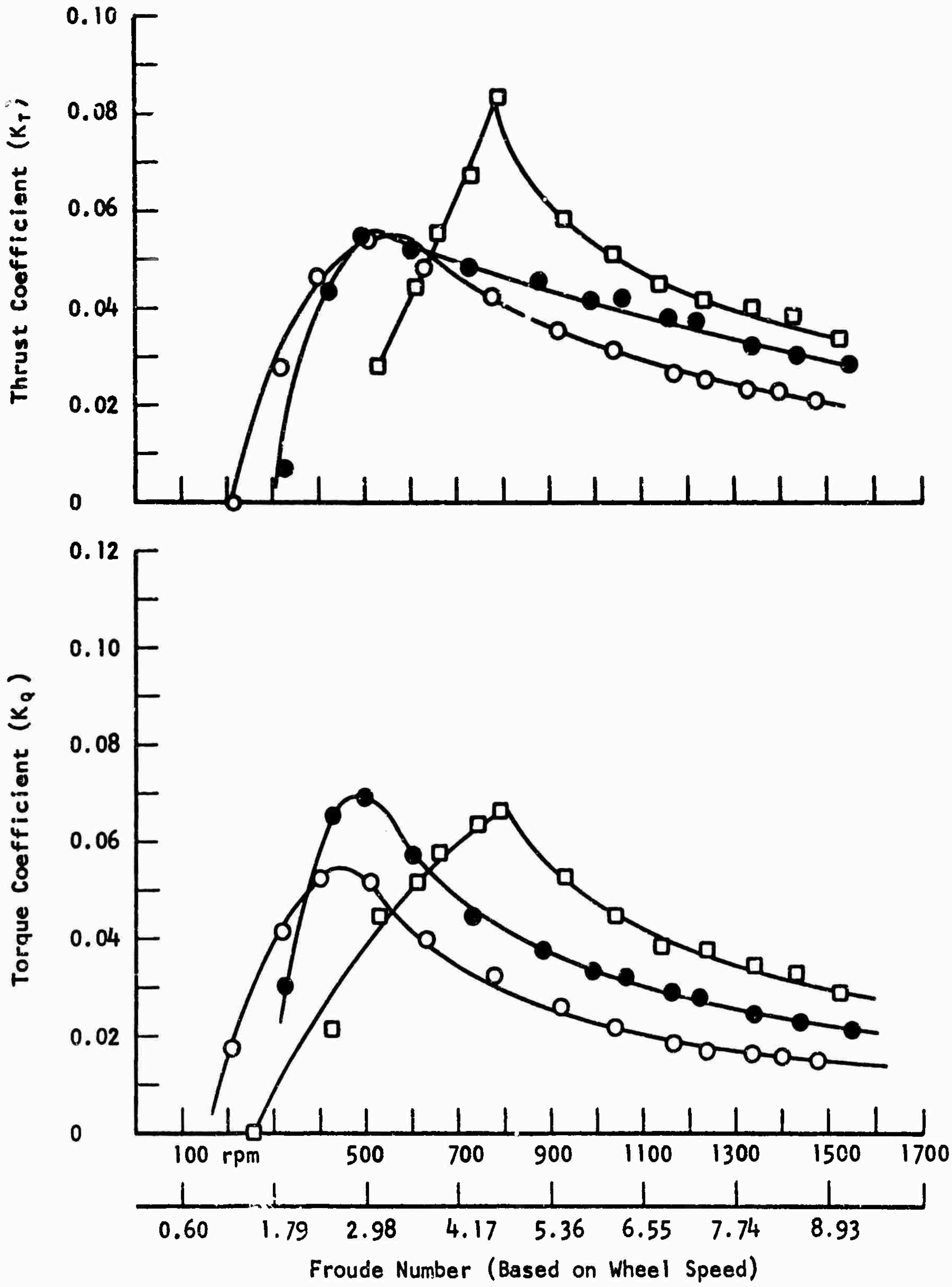

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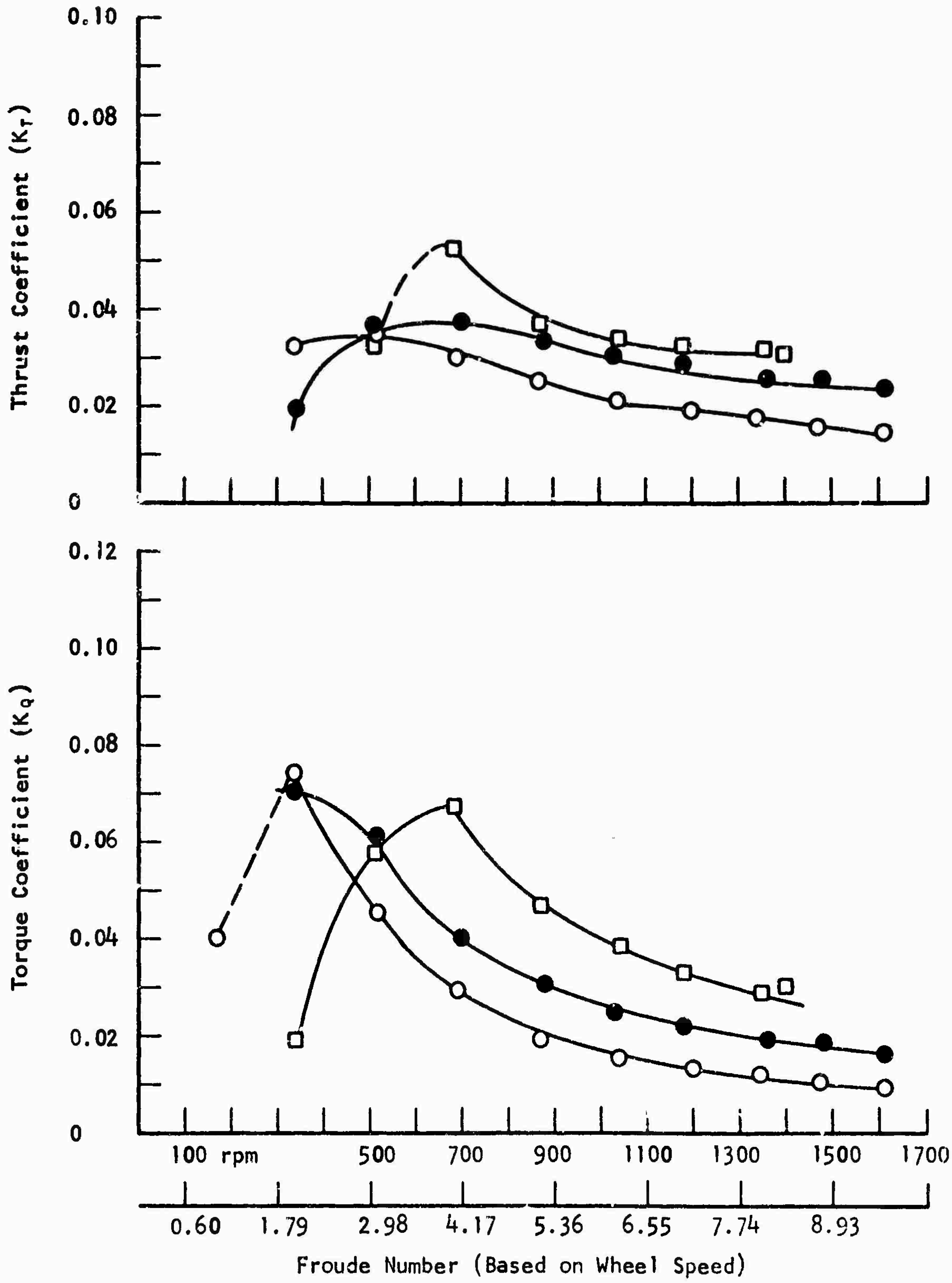

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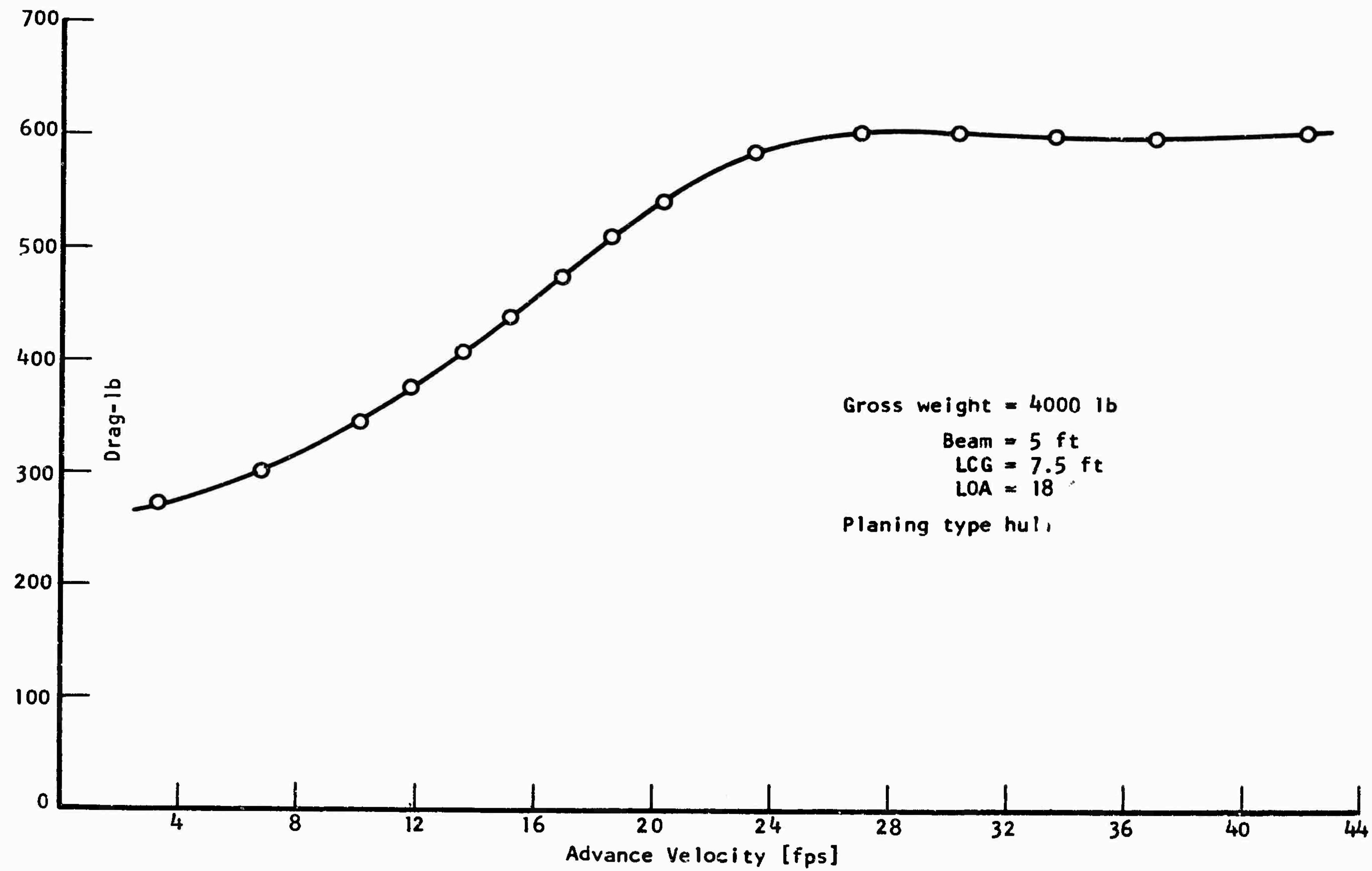

FIGURE 50. DRAG VERSUS ADVANCE VELOCITY FOR A PROTOTYPE VEHICLE WITH A PLANING HULL

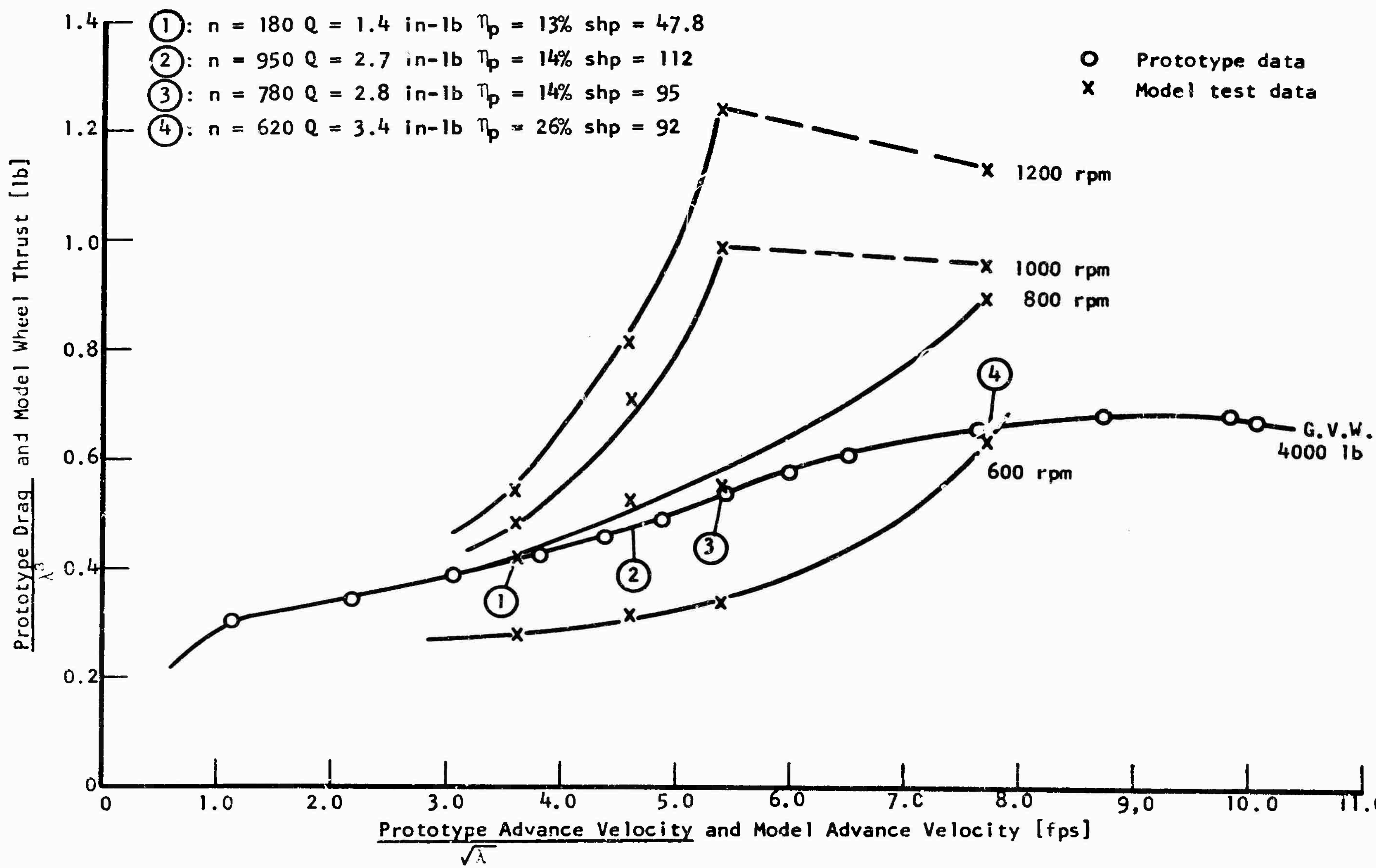

FIGURE 51. REDUCED DRAG CURVE OF PROTOTYPE VEHICLE WITH SOME MODEL TEST DATA SHOWN FOR PERFORMANCE MATCHING

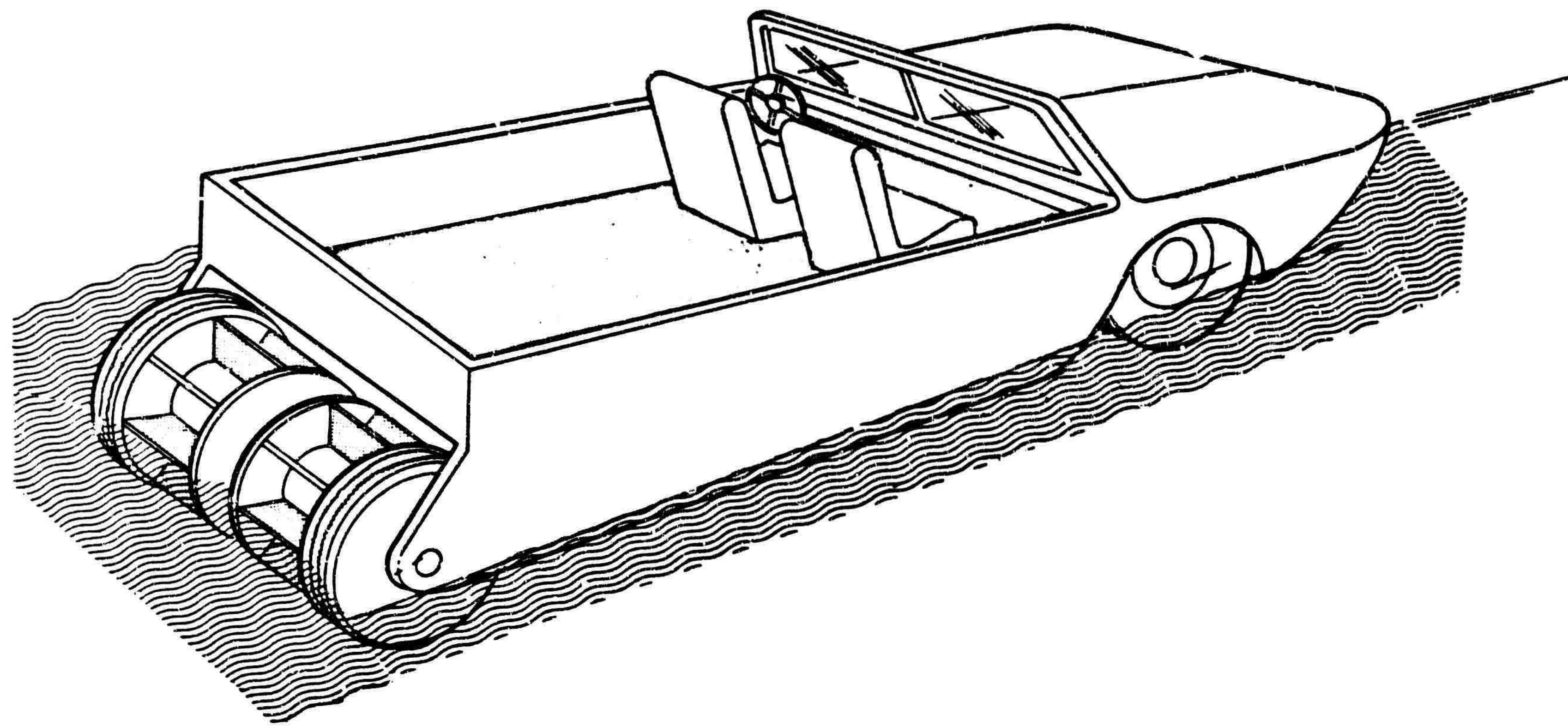

FIGURE 52. SIMPLIFIED CONCEPT DRAWING OF A HIGH SPEED AMPHIBIOUS RECONNAISSANCE VEHICLE UTILIZING A PADDLE WHEEL PROPULSION SYSTEM. NOTE THAT FRONT WHEELS ARE RETRACTABLE FOR MAXIMUM WATER SPEED AND REASONABLE OFF-ROAD PERFORMANCE

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)

Davidson Laboratory, Stevens Institute of Technology
Hoboken, New Jersey 07030

2a. REPORT SECURITY CLASSIFICATION

UNCLASSIFIED

2b. GROUP

3. REPORT TITLE

A MODEL STUDY OF THE HYDRODYNAMIC CHARACTERISTICS OF A SERIES OF PADDLE-WHEEL PROPULSIVE DEVICES FOR HIGH-SPEED CRAFT

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final Report

5. AUTHOR(S) (First name, middle initial, last name)

Gilbert A. Wray and James A. Starrett

6. REPORT DATE

June 1970

7a. TOTAL NO. OF PAGES

114

7b. NO. OF REFS

11

8a. CONTRACT OR GRANT NO.

DAAE-07-69-0356

b. PROJECT NO.

c.

d.

9a. ORIGINATOR'S REPORT NUMBER(S)

SIT-DL-70-1428

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

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11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY

Department of Defense
Washington, D. C. 20301

13. ABSTRACT

This report covers an investigation of the hydrodynamic characteristics of a series of scale models of paddle wheels with fixed radial blades, designed for speeds in excess of 20 knots.

The results indicate that a six-bladed wheel has higher propulsive efficiency and thrust than a twelve-bladed wheel. Peak efficiency is in the neighborhood of 41 percent and occurs at slip values of 30 to 40 percent. Thrust increases with immersion depth, within the range tested (16 percent of the wheel diameter immersed). There is a slight break in the thrust curve over a span of 10-percent slip, after which the thrust again increases with increasing slip.

There is evidence of scale distortion, and it is felt that the present model, with a scale factor of 8.5 to 1, may have been too small.

UNCLASSIFIED
Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Hydrodynamics Amphibians Paddle Wheels Propulsion						